FINAL

Corrective Action Plan for the Risk-Based Remediation Site ST-27

Charleston Air Force Base
South Carolina

Volume I: Report

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

Charleston Air Force Base
South Carolina

August 1997

Walton, Norman

From: Hansen, Jerry E, Mr, HQAFCEE [Jerry.Hansen@HQAFCEE.brooks.af.mil]
Sent: Tuesday, August 08, 2000 10:16 AM
To: 'nwalton@dtic.mil'
Subject: Distribution statement for AFCEE/ERT reports

Norman, This is a followup to our phone call. The eight boxes of reports you received from us are all for unlimited distribution. If you have any questions, you can contact me at DSN 240-4353.

FINAL

CORRECTIVE ACTION PLAN FOR THE RISK-BASED REMEDIATION OF SITE ST-27

VOLUME I: REPORT

CHARLESTON AIR FORCE BASE
SOUTH CAROLINA

August 1997

Prepared for

Air Force Center for Environmental Excellence
Brooks Air Force Base
San Antonio, Texas

and

Charleston Air Force Base, South Carolina

Prepared by
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900, CO 80014
401 Harrison Oaks Blvd., Suite 210, Cary, NC

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EXECUTIVE SUMMARY

GENERAL OVERVIEW

A comprehensive site investigation addressing soils and groundwater contaminated with fuel hydrocarbons and nonfuel organic compounds at Installation Restoration Program (IRP) Site ST-27, was conducted at Charleston Air Force Base (AFB), South Carolina, by Parsons Engineering Science, Inc. (Parsons ES). Field work was conducted to complete a corrective action plan (CAP) in support of a risk-based remediation decision for Site ST-27. Characterization field efforts for this investigation were conducted by Parsons ES from July 1995 through January 1996. Subsequent pilot testing of various low-cost remedial technologies, initiated in January 1996, is ongoing.

The risk-based approach for remediation of Site ST-27 is sponsored by the United States (US) Air Force Center for Environmental Excellence (AFCEE) at Brooks AFB, Texas under contract F41624-93-C-8044. The Site ST-27 risk-based remedial evaluation is a component of a multi-site AFCEE initiative. AFCEE's nationwide initiative demonstrates how quantitative fate and transport calculations and risk evaluation, based on site-specific data, can be integrated. Consequently, this integration allows for rapid determination of the type and magnitude of corrective action required at a site to minimize contaminant migration, receptor exposure, and subsequent health risks to the potential receptors. Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks to human health and the environment posed by subsurface petroleum fuel spills.

IRP Site ST-27 is located in the north-central portion of the Base adjacent to Building 575, an aircraft maintenance hangar, and several solid waste management units (SWMUs) related to aircraft and maintenance operations. The site is located within a designated aircraft maintenance area located west of the major taxiways for primary Runway 15/33 and is capped by 8 to 14 inches of concrete. Site ST-27 consists of several underground storage tanks (USTs) used to store JP-4 jet fuel, JP-8 jet fuel, motor gasoline (MOGAS), and diesel fuel to support aircraft operations at the Base. Releases from the site's leaking UST systems have contaminated soil and groundwater with fuel hydrocarbons. In addition to site-related fuel contamination, nonfuel organic compounds from adjacent SWMUs have been measured in soil and groundwater at and immediately upgradient from Site ST-27.

The CAP for Site ST-27 follows South Carolina Department of Health and Environmental Control (SCDHEC, 1995) guidance for implementing risk-based corrective actions (RBCA) for petroleum releases in the State. The RBCA guidance outlines a tiered approach for establishing corrective action requirements at specific sites. The tiered approach is based on an evaluation of potentially completed receptor exposure pathways from contaminated site media under both current and future land use scenarios.

One objective of the CAP is to document any potential current risks to human health and the environment (i.e., ecological receptors) due to exposure to chemical contaminants originating from Site ST-27. The CAP also addresses the potential future risks to human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. The overall objective of the CAP is to develop and present a recommended risk-based remedial approach for fuel hydrocarbon and nonfuel organic contamination in soils and groundwater at and downgradient from Site ST-27 that is protective of both human health and the environment. This information can be used by the Air Force to support a variance for a Groundwater Mixing Zone that will allow the State drinking water standards to be exceeded at this site.

Overview of Project Activities

It is the intent of the Air Force to pursue a site-specific, risk-based remediation of Site ST-27 in conformance with the tiered-approach framework established by SCDHEC (1995). The activities conducted pursuant to 1) classifying the release, 2) determining the need for and type of any interim corrective action, and 3) establishing the level of evaluation necessary to define risk-reduction requirements at this site included characterizing:

- The nature and extent of fuel hydrocarbon and nonfuel organic contamination at the site;
- The locations of potential groundwater recharge and discharge areas;
- The local geology, hydrogeology, and hydrology that may affect contaminant transport;
- The proximity of the site to drinking water aquifers, surface water, and other sensitive environmental resources;
- The expected persistence, mobility, chemical form, and environmental fate of hazardous substances in soils and groundwater under the influence of natural physical, chemical, and biological processes;
- The current and potential future uses of the site and its vicinity, including groundwater, and the likelihood of exposure of receptors to other potentially impacted environmental media over time;
- The potential risks associated with chemical contamination under current and foreseeable future conditions;
- The long-term target remedial objectives and chemical-specific concentration goals required to protect human health and the environment; and
- The treatability of residual and dissolved fuel hydrocarbon and nonfuel organic contamination using low-cost source-reduction technologies such as bioventing and soil vapor extraction (SVE).

Summary of Proposed Type of Cleanup

Several remedial approaches that rely both on natural processes and on engineered solutions were evaluated for the site. A site-specific exposure pathways analysis involving environmental media impacted by chemical contamination at and migrating from Site ST-27 was completed to ensure that existing and predicted future concentrations of hazardous substances would not pose a threat to current and foreseeable future onsite or offsite receptors. The site-specific exposure pathway analyses indicate that only onsite intrusive workers could reasonably be exposed to site-related contamination.

Concentrations of several fuel hydrocarbons measured at Site ST-27 exceed applicable RBCA Tier 1 risk-based screening levels (RBSLs) (SCDHEC, 1995). Tier 1 RBSLs are generic or nonsite-specific risk-based concentrations to be used as a screening tool to initially determine chemicals of potential concern (COPCs). The analytes with site concentrations above the Tier 1 screening levels include:

- Benzene, toluene, ethylbenzene, xylenes (BTEX);
- Naphthalene;
- Chlorobenzene;
- 1,2,4- and 1,3,5-Trimethylbenzene (1,2,4-TMB and 1,3,5-TMB); and
- cis-1,2-Dichloroethylene (cis-1,2-DCE).

Consequently, a comprehensive Tier 2 evaluation was conducted to (1) develop alternate site-specific target levels (SSTLs) to be used to guide the type, magnitude, and timing of corrective action to be implemented at the site, (2) determine whether any unacceptable and imminent threats to human health or the environment exist at the site, (3) establish appropriate points-of-action (POAs) monitoring wells, and (4) select and prepare an initial design of the recommended corrective action, including land use controls, and a long-term monitoring plan (LTMP) to protect human health and the environment.

A site-specific chemical fate assessment was completed as part of the Tier 2 quantitative exposure pathways analysis to identify the potential for, and risks associated with, exposure to chemical contamination over time at the site. The potential for receptor exposure to chemical contamination originating from Site ST-27 over time depends on future site conditions and the persistence, mobility, chemical form, toxicity, and fate of site-related contaminants. Site characterization data relevant to documenting natural chemical attenuation, specifically bioattenuation, were collected and are documented in this CAP. Fate and transport model results were used to predict the exposure-point concentrations of different contaminants over time at the site.

Based upon the Tier 2 assessment and evaluation, Site ST-27 is classified as a Category 5 release. There is currently no demonstrable threat to potential human or ecological receptors, but data indicate that all the soil COPCs and many of the

groundwater COPCs (i.e., benzene, toluene, naphthalene, and 1,2,4-TMB) are present at concentrations that exceed their respective SSTLs.

Although measured concentrations of a few site-related contaminants exceeded the most restrictive Tier 2 SSTLs, the comprehensive Tier 2 evaluation demonstrates that no fuel or nonfuel organic compounds will migrate offsite at concentrations above the Tier 1 RBSLs. Additionally, the Tier 2 evaluation shows that no exposure pathway involving onsite receptors is likely to be complete unless the concrete apron is disturbed or otherwise removed. If this scenario occurs, future onsite intrusive workers could be exposed to contaminants in groundwater via dermal contact (note that all other pathways based on intrusive worker exposure to contaminants in air and soils were determined to be incomplete or negligible). Although the dermal-based exposure pathway could be completed under highly disruptive, intrusive activities, the probability that actual long-term (chronic) worker exposure will occur is low. Deciding to conduct engineered remediation activities at this site on the basis of this exposure pathway would be considered a conservative risk management decision, especially considering that this exposure pathway could be easily interrupted by employing basic personal protective equipment (PPE) common to excavation work (e.g., boots, pants, long-sleeved shirts, and rubber gloves). Regardless, the interim soil remedial action (discussed below) implemented at Site ST-27 coupled with ongoing natural chemical attenuation processes should be sufficient to reduce dissolved COPC concentrations to levels below their most restrictive Tier 2 SSTL (i.e., the health-based SSTL assuming intrusive worker exposure to groundwater via dermal contact) by about the year 2017. Therefore, the Air Force intends to base long-term cleanup objectives on the health-protective SSTLs, rather than pursue compliance with Tier 1 RBSLs.

The comparative remedial analysis presented in this CAP shows that the best combination of risk reduction and low cost remediation can be achieved by implementing SVE followed by bioventing to treat residual subsurface sources and natural chemical attenuation of dissolved contamination. Based on pilot test data, implementation of an expanded SVE system at Site ST-27 (as the interim soil remedial action) will reduce concentrations of volatile organic compounds (VOCs) in source area soil gas to below levels that present a potential explosive hazard within 3 to 6 months. In addition to mitigating potential explosive hazards, soil remediation by SVE will ensure that residual subsurface contaminant sources do not present an inhalation hazard should the concrete apron be disturbed or removed as part of future land use plans. Once soil gas hydrocarbon concentrations have been reduced, the SVE system will be reconfigured as an air injection bioventing system. Because no off-gas treatment is required with an air injection bioventing system, it is a more cost-effective soil remedial technology to use to reduce remaining soil COPC concentrations to below the Tier 2 soil leaching (i.e., nonhealth-based) SSTLs within 1 to 2 years.

In summary, the quantitative Tier 2 evaluation demonstrates that use of these low-cost source reduction technologies (i.e., SVE and then bioventing) reduces the time to achieve the most restrictive Tier 2 SSTLs in underlying groundwater. Once subsurface soil contaminant concentrations have been effectively reduced, natural chemical attenuation processes will reduce dissolved COPC concentrations below health-protective Tier 2 SSTLs by approximately the year 2007 (i.e., 8 years before Tier 2 SSTLs would be achieved without bioventing). The use of low-cost source reduction

technologies decreases the length of time required to achieve Tier 2 SSTLs in all media at minimal cost. To confirm that the predicted degree of remediation is being attained and to ensure that no unacceptable receptor exposures to chemical contamination could occur at the site, a LTMP is included in this CAP.

The Air Force intends to use the findings of this CAP to support an application for a "Groundwater Mixing Zone" variance which will allow exceedance of drinking water standards at this site. This CAP will demonstrate that engineered source reduction and natural attenuation will effectively eliminate site-specific risks due to fuel contamination.

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AMC	Air Mobility Command
ASTM	American Society for Testing and Materials
AW	Airlift Wing
bgs	below ground surface
BTE	benzene, toluene, ethylbenzene
BTEX	benzene, toluene, ethylbenzene, xylenes
CAH	chlorinated aliphatic hydrocarbon
CO_2	carbon dioxide
COPC	chemical of potential concern
CSM	conceptual site model
CAP	corrective action plan
DAF	dilution/attenuation factor
DCE	dichloroethene
DO	dissolved oxygen
EA	EA Engineering, Science, & Technology, Inc.
ES	Engineering-Science, Inc.
ET	evapotranspiration
°F	degrees Fahrenheit
FS	feasibility study
ft/ft	foot per foot
ft/min	foot per minute
ft/yr	feet per year
GEL	General Engineering Laboratories
HAIW	horizontal air injection well
HNUS	Halliburton NUS Corporation
HVW	horizontal vent well
ICE	internal combustion engine
IRP	Installation Restoration Program
IRIS	Integrated Risk Information System
K_d	distribution partition coefficient
K	octanol-carbon partitioning coefficient

LEL	lower explosive limit
LNAPL	light nonaqueous-phase liquid
LTM	long-term monitoring
LTMP	long-term monitoring plan
MCL	maximum contaminant level
MDL	method detection limit
µg/kg	microgram per kilogram
µg/L	microgram per liter
mg	milligram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
mm Hg	millimeters of mercury
MOGAS	motor gasoline
MPA	monitoring point A
MPB	monitoring point B
MPC	monitoring point C
msl	mean sea level
NCP	National Contingency Plan
NMRL	National Risk Management Research Laboratory
NOAA	National Oceanographic and Atmospheric Administration
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
Parsons ES	Parsons Engineering Science, Inc.
PEL	permissible exposure limit
PID	photoionization detector
POA	point-of-action
ppmv	parts per million per volume
PQL	practical quantitation limit
psi	pounds per square foot
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RBSL	risk-based screening level

RDL	reliable detection limit
redox	reduction/oxidation
RFI	RCRA facility investigation
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RME	reasonable maximum exposure
SAIC	Science Applications International Corporation
SAP	sampling and analysis plan
SCDHEC	South Carolina Department of Health and Environmental Control
scfm	standard cubic feet per minute
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SQL	sample quantitation limit
SSTL	site-specific target level
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TCE	trichloroethene
TCLP	toxicity-characteristic leaching procedure
TEPH	total extractable petroleum hydrocarbons
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TVH	total volatile hydrocarbons
TVPH	total volatile petroleum hydrocarbons
TWA	time-weighted-average
U	undetected
US	United States
USGS	US Geological Survey
UST	underground storage tank
VOCs	volatile organic compounds
VW	vent well

SECTION 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering-Science, Inc. (ES), was retained by the United States (US) Air Force Center for Environmental Excellence (AFCEE) to prepare a corrective action plan (CAP) in support of a risk-based remediation decision for soil and groundwater contaminated with fuel hydrocarbons and nonfuel organic compounds at Site ST-27 at Charleston Air Force Base (AFB), South Carolina. Site ST-27 consists of several underground storage tanks (USTs) used to store JP-8 jet fuel, motor gasoline (MOGAS), and diesel fuel to support aircraft operations at the Base. One or more fuel releases from leaking USTs and fuel transfer lines have contaminated site soil and groundwater with fuel hydrocarbons. In addition to site-related fuel contamination, nonfuel organic compounds from adjacent sites have been measured in soil and groundwater at and immediately upgradient from Site ST-27.

Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks to human health and the environment posed by subsurface petroleum fuel spills. This CAP is prepared as part of a multi-site initiative sponsored by AFCEE to develop a protocol on how risk information and quantitative fate and transport calculations based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at fuel-contaminated sites to minimize contaminant migration and potential receptor risks. Site ST-27 is one of several sites nationwide that will be used as a case study in the development of the protocol.

This CAP provides the documentation elements specified by the Underground Storage Tank Program of the South Carolina Department of Health and Environmental Control (SCDHEC, 1995) for both Tier 1 and Tier 2 risk-based assessments and evaluations. The SCDHEC guidance is based on the American Society for Testing and Materials' (ASTM, 1995) *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (E1739-95), which outlines a tiered approach for establishing corrective action requirements at specific sites based on an evaluation of potential receptor exposures to chemical contamination at or migrating from the release site. SCDHEC (1995) requires releases to be classified with respect to the timeframe in which potential receptors could be exposed to site-related contamination. Prioritization is an ongoing process based on available information, such as extent of contamination, contaminant fate and transport estimates, and effectiveness of any interim remedial actions.

Once a release has been initially classified, the site should be subject to a Tier 1 evaluation. A Tier 1 evaluation is essentially a screening-level assessment where contaminant concentrations measured in site media are compared to nonsite-specific (i.e., generic) values, based on conservative receptor exposure factors, potential receptor exposure pathways, and land use assumptions, to identify appropriate corrective actions. Tier 1 risk-based screening levels (RBSLs) have been defined for both unrestricted (i.e., residential) and industrial/commercial land use assumptions. In the event that measured site concentrations exceed the applicable Tier 1 RBSLs and remediation to Tier 1 RBSLs is not practicable, either an interim corrective action or a Tier 2 evaluation may be pursued. If an interim corrective action is deemed unnecessary, a Tier 2 evaluation should be conducted to establish reasonable, risk-based target cleanup objectives for a specific site. A Tier 2 evaluation is more comprehensive than a Tier 1 analysis because it requires quantitative contaminant fate and transport calculations and the development of site-specific remediation goals for potential receptor exposure pathways based on reasonable exposure assumptions and actual land use considerations. Tier 2 site-specific target levels (SSTLs) are based on the outcome of a predictive exposure pathways analysis to evaluate current and potential future human health risks and short-term and long-term fate of the contaminants at the site. Although Tier 2 evaluations usually involve more rigorous analysis and may require use of institutional controls to ensure that exposure conditions do not change over time, they should result in a more focused remediation of those contaminants that may actually pose a risk to potential receptors (SCDHEC, 1995).

If measured site concentrations exceed the proposed Tier 2 SSTLs and remediation to Tier 2 SSTLs is not practicable, either an interim corrective action or a Tier 3 evaluation may be completed. If an interim corrective action is not deemed necessary, a Tier 3 evaluation should be conducted to establish reasonable, risk-based target cleanup objectives for a specific site. A Tier 3 risk-based evaluation involves the use of more sophisticated mathematical models than a Tier 2 evaluation to derive site-specific remediation goals. Appropriate points-of-action (POAs) and a long-term monitoring plan (LTMP) are key elements of a corrective action based on a tiered approach.

This CAP documents the reasonable potential risks to human health and the environment (i.e., ecological receptors) due to exposure to chemical contaminants originating from Site ST-27 under current conditions. The CAP also estimates the potential risks to future human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. Finally, the CAP develops and describes a recommended remedial approach for fuel hydrocarbon and nonfuel organic contamination in soils and groundwater at and downgradient from Site ST-27 that can achieve the Tier 2 SSTLs. The Air Force intends to use the findings of this report to support a Groundwater Mixing Zone variance which will allow exceedance of drinking water standards in the most contaminated potion of the site. In accordance with Groundwater Mixing Zone Guidance South Carolina Code of Regulations Chapter 61-68, the Air Force believes Site ST-27 is an excellent candidate for a variance. This CAP is being submitted for review and approval in accordance with SCDHEC (1995) program requirements.

1.2 REPORT ORGANIZATION

This CAP consists of 11 sections, including this introduction, and 9 appendices, presented in two volumes. Site background, including operational history and a review of environmental site investigations conducted to date, are provided in the remainder of this section. Section 2 summarizes the 1995/1996 site characterization activities performed by Parsons ES. Physical characteristics of Site ST-27 and surrounding environs are described in Section 3. A Tier 1 evaluation is completed in Section 4 to identify those site contaminants that are considered chemicals of potential concern (COPCs). Section 5 summarizes the nature and extent of COPC contamination at the site. Section 6 addresses the effects of natural chemical attenuation processes that are documented to be occurring at the site, and presents quantitative fate and transport and exposure pathways analyses. The comprehensive Tier 2 evaluation, including the development of SSTLs, is detailed in Section 7. Section 8 presents contaminant treatability pilot test results for bioventing and soil vapor extraction (SVE), and evaluates these low-cost source reduction technologies. Section 9 presents a comparative analysis of three candidate remedial alternatives. Section 10 is a more detailed implementation plan for the recommended remedial alternative, and a detailed LTMP. Section 11 presents references used in preparing this CAP. Sections 1 through 11 are presented in Volume I of this CAP.

Appendix A presents soil gas, soil, and groundwater analytical results and data validation results from the ES (1993) bioventing pilot test, the 1995/1996 risk-based sampling event conducted by Parsons ES, and the Parsons ES 1996 SVE pilot test. Appendix B contains the boring logs, well construction diagrams, and well development data for all sampling activities completed by Parsons ES at Site ST-27. Aquifer test data and analyses are presented in Appendix C. Appendix D presents the algorithms used to derive Tier 1 RBSLs. Appendix E includes the quantitative calculations and fate and transport model results used in the predictive chemical fate assessment. Appendix F presents the derivation of Tier 2 SSTLs. Appendix G presents the source-reduction treatability test results, and Appendix H summarizes the screening and development of remedial alternatives considered in detail within this CAP. Appendix I presents a site-specific sampling and analysis plan (SAP) for use during extended SVE treatment and long-term monitoring at the site. The nine appendices to this CAP are included in Volume II.

1.3 SITE BACKGROUND

Charleston AFB is the headquarters for the US 437th Airlift Wing (AW), a strategic unit of the Air Force's Air Mobility Command. The 437th comprises more than 40 percent of the Department of Defense's all-weather strategic airdrop force, and provides the Joint Chiefs of Staff the only C-17 rapid-response alert force capable of world-wide operations. The operational areas served by the 437th AW are global, and include Europe, the Middle East, Africa, and Latin America. Charleston AFB also hosts the 315th AW (an Associate Reserve component), the 1st Combat Camera Squadron, and the 158th Fighter Interceptor Group.

The Base is located in North Charleston, approximately 10 miles north of the Charleston Harbor and the historic district in downtown Charleston, South Carolina (Figure 1.1). The Base encompasses 3,731 acres of land between the Ashley and Cooper Rivers in Charleston County and shares runways with Charleston International Airport. The Base and adjacent Charleston County Aviation Authority properties of about 1,400 acres are operated through a joint-use agreement first negotiated in 1956. The Base is generally bordered by Ashley Phosphate Road on the north, Interstate 26 on the east, Interstate 526 on the south, and Dorchester Road on the west. Approximately 4,500 active-duty military personnel are assigned to Charleston AFB. Of this total, approximately 1,900 reside on-Base, while the remaining 2,600 live in the surrounding community. In addition to active-duty personnel, 3,600 local Air Force reservists serve in the 315th AW. The Base also employs approximately 1,800 civilian workers.

Site ST-27, which has been identified as an Installation Restoration Program (IRP) site, is located in the north-central part of the Base, on the western edge of the aircraft maintenance apron and adjacent to the Building 575 maintenance hangar. Figure 1.2 shows the location of Site ST-27 on Charleston AFB. The areas immediately around IRP Site ST-27 and Building 575 include eight solid waste management units (SWMUs), as identified in the Charleston AFB Resource Conservation and Recovery Act (RCRA) Part B permit and in the Base-wide RCRA Facility Investigation (RFI) Work Plan [Halliburton NUS Corporation (HNUS), 1993]. Site ST-27 has been variously designated as IRP Site 20 or SWMU 145 in other documents.

Nearby SWMUs include the Building 575 washrack (SWMU 20), Building 575 sand trap (SWMU 21), Building 575 open stormwater drain/sump system (SWMU 22), Building 575 sump 1 (SWMU 23), Building 575 sump 2 (SWMU 24), Building 575 oil/water separator (SWMU 25), Building 575 oil holding tank (SWMU 26), and the Building 575 waste oil tank (SWMU 27). Because all of these SWMUs are in very close proximity to Site ST-27, the risk-based investigation for the site specifically targeted SWMU 145, but also addressed the areas around the adjacent SWMUs. The adjacent areas are shown on Figure 1.3.

1.3.1 Operational History

Several petroleum USTs have been or currently are operated at Site ST-27 (SWMU 145) on the north side of the Building 575 maintenance hangar. In 1977, a 10,000-gallon UST, currently used to store JP-8, was installed in a 6-inch-thick concrete vault. This UST remains in service at the site. A 3,000-gallon UST and a 1,000-gallon UST were used previously at the site to store JP-4 jet fuel and MOGAS, respectively. Both of these USTs were operated for approximately 30 years before they were removed from service in January 1988. Prior to removing the USTs, the Air Force had suspected that the 3,000-gallon JP-4 jet fuel UST was leaking due to a constant flux of water entering the tank. The suspected leak in the 3,000-gallon UST was confirmed in January 1988, when the tank was removed and soils contaminated with JP-4 jet fuel

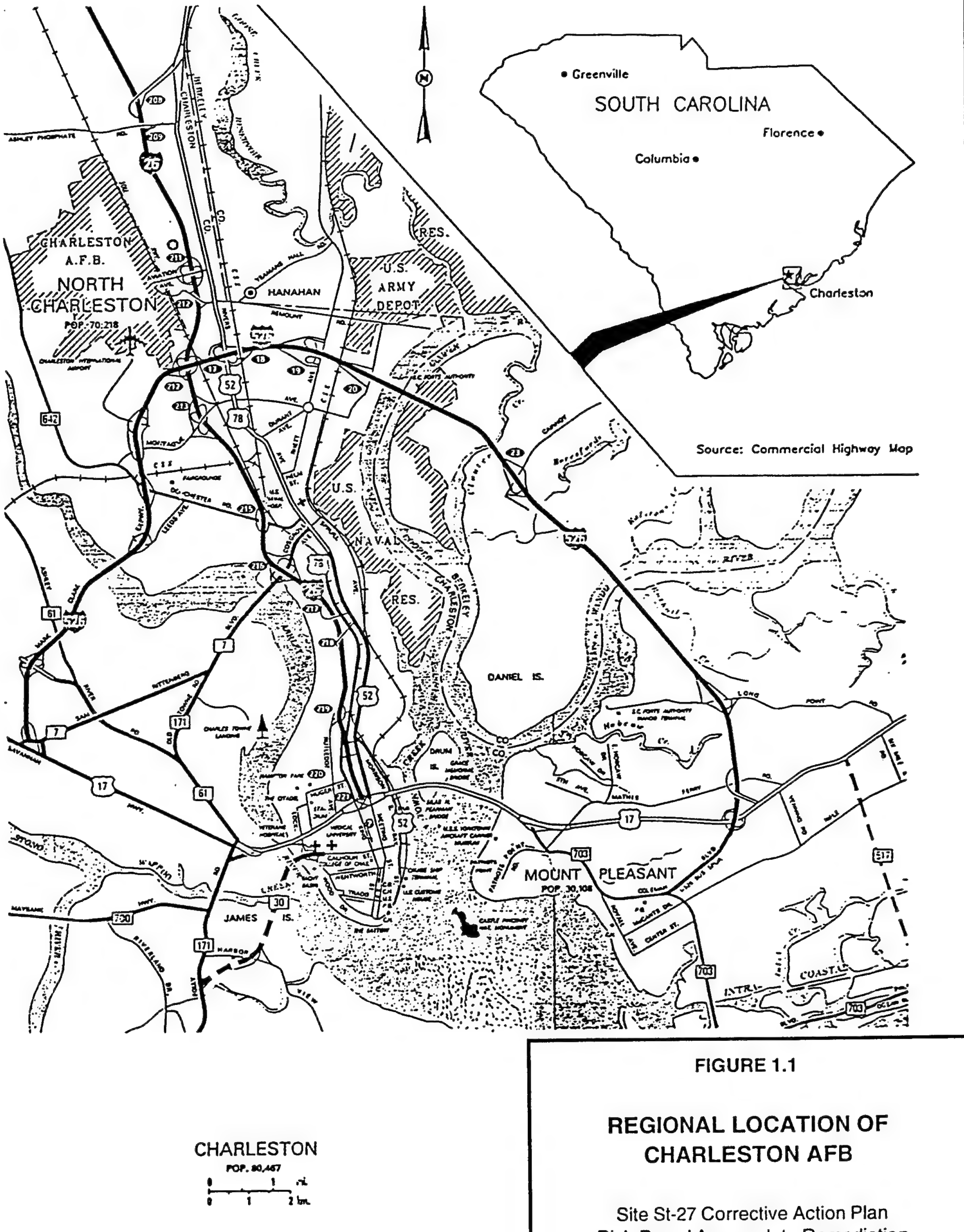

FIGURE 1.1

REGIONAL LOCATION OF CHARLESTON AFB

Site St-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

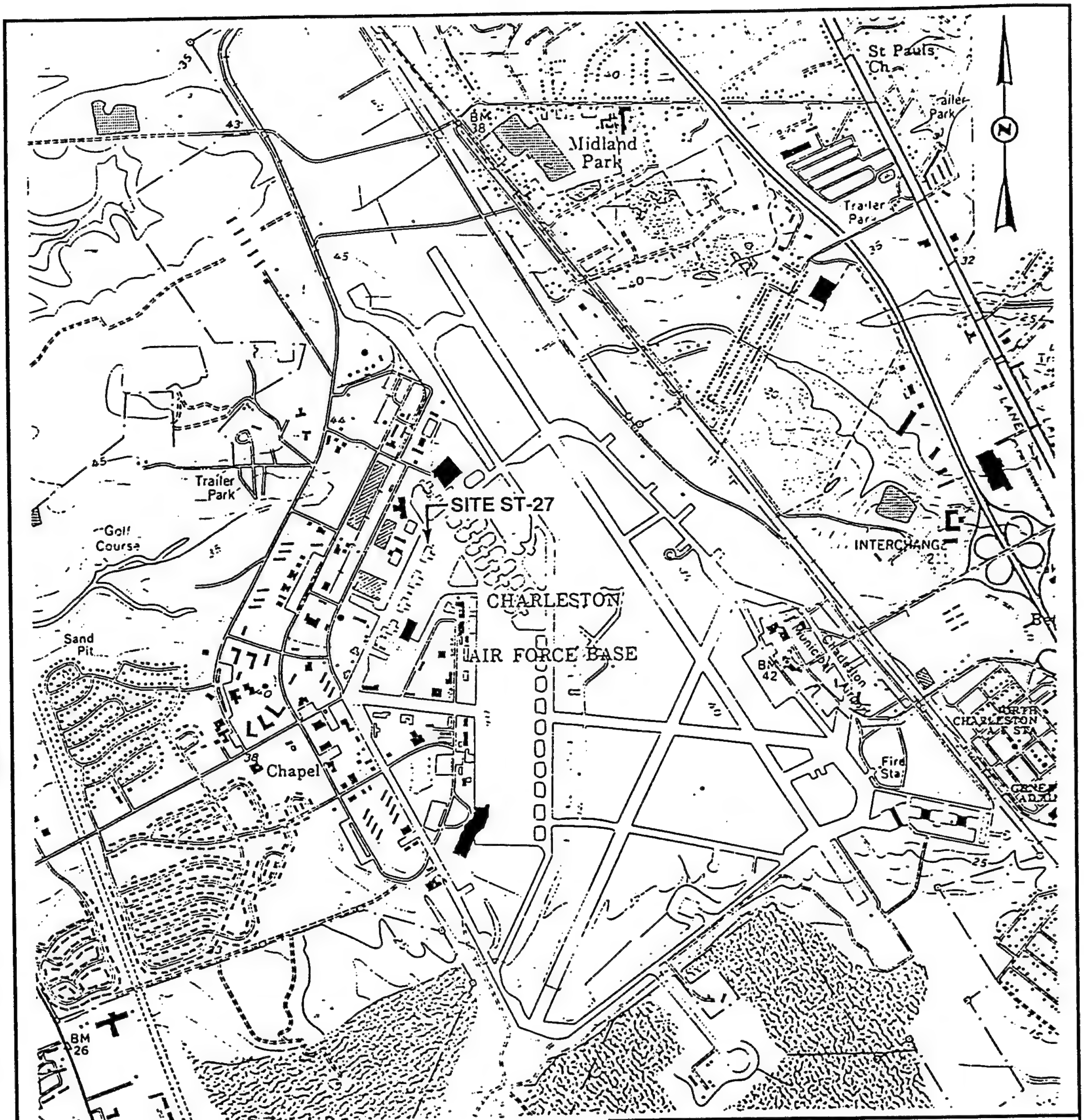

FIGURE 1.2

SITE LOCATION

Site St-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

Map Source:
Ladson, South Carolina Quadrangle
(7.5 Minute Series)

2000 1000 0 2000'
Approximate Scale in Feet

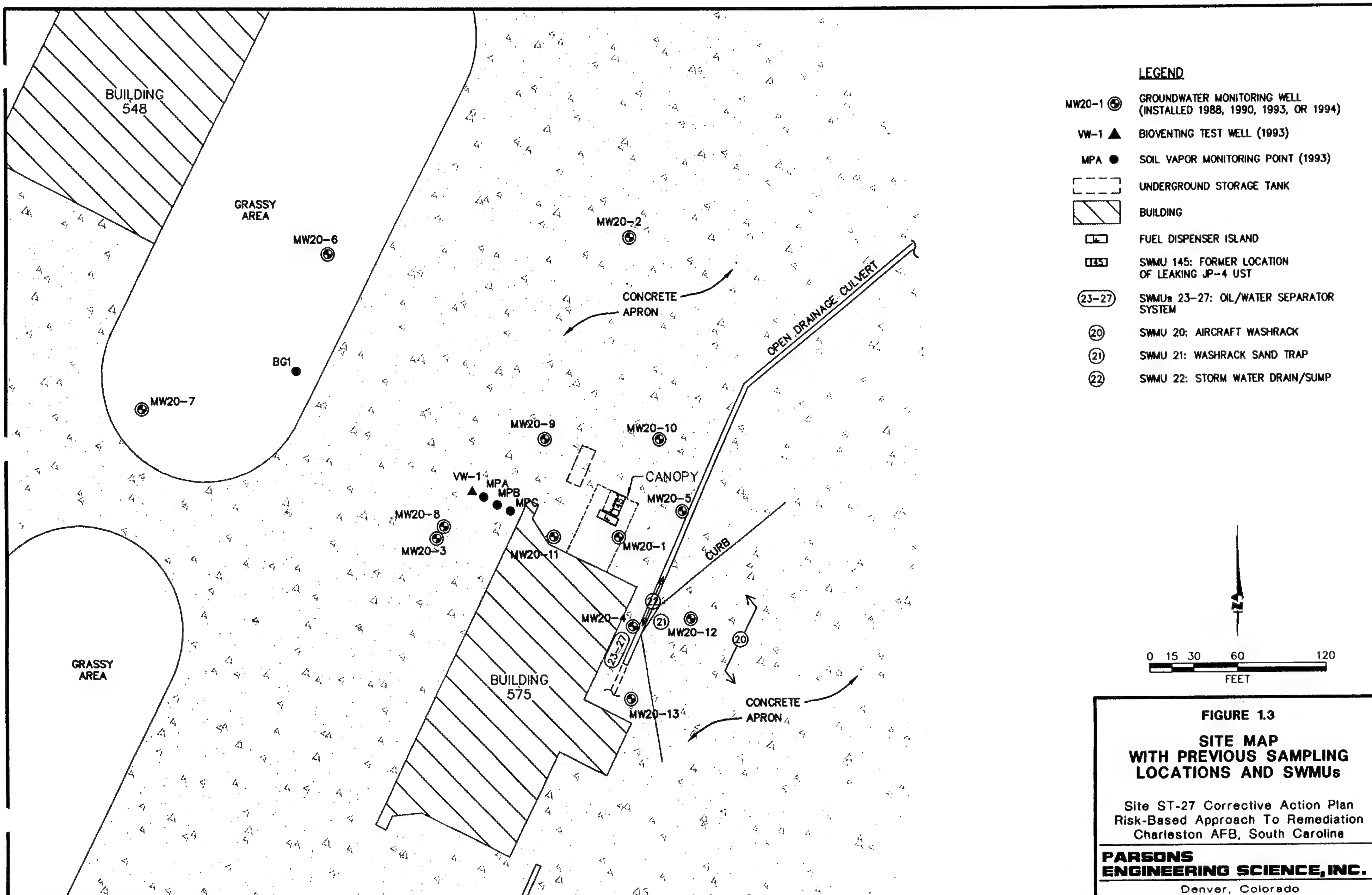

FIGURE 1.3

SITE MAP WITH PREVIOUS SAMPLING LOCATIONS AND SWMUs

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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were discovered. The 1,000-gallon MOGAS tank, which was removed at the same time, reportedly showed no signs of leakage. According to Base personnel, some of the most heavily contaminated soils around the former USTs at Site ST-27 were excavated and disposed of during the tank removals [General Engineering Laboratories (GEL), 1988]. The quantity of contaminated soils excavated and removed from the site was not reported.

Two 4,000-gallon fiberglass petroleum USTs were installed at the locations of the former 3,000-gallon and 1,000-gallon USTs at Site ST-27 in April 1988. One of these tanks stores MOGAS, and the other stores diesel fuel. In addition to the 10,000-gallon JP-8 UST installed in 1977, these two 4,000-gallon tanks are currently operating as part of the Building 575 UST system. During leak testing in January 1996, it was discovered that both MOGAS and diesel were leaking from the tanks or subsurface transfer lines. The source of the MOGAS contamination was due to bad pipe coupling. The pipe coupling has since been replaced and the MOGAS tank has fuel in it. The source of the diesel leak has not been found. The diesel tank has been emptied with no intent to reuse it, so technically it has been removed from service. The entire site is scheduled to be decommissioned in 1997. The locations of the three existing USTs at Building 575 are shown on Figure 1.3.

Adjacent SWMUs are part of the Building 575 oil/water separation system, which operated under the RCRA permit. The system is designed to collect and treat wash wastewater prior to discharge to the sanitary sewer system. SWMU 20 (the Building 575 washrack) was originally constructed on part of the taxiway as an area to be used for washing mobile and power equipment. This unit was subsequently modified and expanded to be used to wash aircraft. Operational records indicate that cleaning agents such as PD-680 solvent, alkali, varsol, striptone, and biodegradable soaps have been or are currently used to wash equipment and aircraft at the Building 575 washrack, served by the oil/water separation system (HNUS, 1993). Striptone consists primarily of methylene chloride (72 percent), although other organic compounds such as methanol, alkyl aryl sulfonate, and monoethylamine are present. Wastewater, which contains the cleaning agents used at the washrack, is discharged to SWMU 21, the Building 575 sand trap. Wastewater from SWMU 21 is then conveyed in a 4-inch-diameter cast iron pipe to Building 575 sump 1 (SWMU 23). Approximately 18 feet of the pipe between SWMU 21 and SWMU 23 is located within SWMU 22, the Building 575 stormwater conveyance sump. SWMU 22 sump is a 2-foot-deep by 2-foot-wide concrete storm drain trench covered with a 10-inch-thick wooden grate (see Figure 1.3 for location of the sump and associated drainage culvert system). Wastewater from SWMU 23 is then pumped to SWMU 25, Building 575 aboveground oil/water separator. All oil separated from the wastewater at this point is stored in aboveground holding tanks (SWMUs 26 and 27). The remaining liquid wastes are routed to SWMU 24, Building 575 sump 2, before being discharged into the sanitary sewer (HNUS, 1993). These SWMUs are shown on Figure 1.3.

1.3.2 Previous Remedial Investigations

1.3.2.1 Site ST-27

Several phases of environmental investigations have been conducted by various contractors at Site ST-27. After the two USTs were removed and a fuel release was confirmed at Site ST-27 (January 1988), the Base contracted with GEL of Charleston, South Carolina, to perform an initial hydrogeologic investigation of the site in June

1988. GEL (1988) installed 14 shallow, hand-augered borings and 5 shallow groundwater monitoring wells (MW20-1 through MW20-5) to assess the impact of the tank leak on soil and groundwater quality. The locations of these initial groundwater monitoring wells are shown on Figure 1.3.

Groundwater contamination was detected in four of the five wells. The highest concentration of dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX) was detected in well MW20-3 at 43,630 micrograms per liter (μg/L). No BTEX compounds were detected in the groundwater at nearby well MW20-2 at that time. Although no measurable thicknesses of light nonaqueous-phase liquid (LNAPL) were observed, GEL (1988) noted that an oily sheen was present on the surface of groundwater samples collected from wells MW20-1 and MW20-3. The contractor reportedly screened soil samples from the 14 soil borings for the presence of fuel contamination. However, neither the field screening methods nor the results were published in their report.

Following the confirmation of groundwater contamination, Site ST-27 (SWMU 145) was designated as an IRP site for continued investigation under a remedial investigation/feasibility study (RI/FS). Versar, Inc. (1992) conducted an IRP Phase II, Stage 2 RI/FS at the Base during 1989-1991, which included Site ST-27. Versar, Inc. installed three additional groundwater monitoring wells at Site ST-27 in 1990. Two of the wells (MW20-6 and MW20-7) were installed in locations presumed to be downgradient from existing wells, while the third well (MW20-8) was installed with a deep-screened interval to monitor the lower portions of the shallow aquifer. Two soil samples were collected for laboratory analyses from the soil boring for well MW20-8. The locations of these permanent groundwater monitoring wells also are shown on Figure 1.3. Versar, Inc. (1992) sampled groundwater from the three new wells and the five existing wells in 1990. Additionally, a sample of LNAPL was collected from well MW20-1 and analyzed for BTEX constituents. Analytical results indicated that the maximum total BTEX concentration in groundwater had declined slightly from 43,630 to 34,300 μg/L at well MW20-3. The two new site-perimeter wells, MW20-6 and MW20-7, showed no detectable concentrations of BTEX compounds. Well MW20-2, which showed no detectable BTEX in 1988, contained 262 μg/L of total BTEX in 1990 (Versar, Inc., 1992). The concentrations of each of the BTEX compounds in the collected LNAPL sample were as follows: benzene, 1,100 μg/L; toluene, 4,100 μg/L; ethylbenzene, 1,600 μg/L; and xylenes, 11,000 μg/L. As described in more detail in Section 5, these concentrations are significantly below those expected in "fresh" MOGAS and above those expected in "fresh" JP-4 jet fuel.

EA Engineering, Science, & Technology, Inc. (EA, 1993) performed a supplemental groundwater investigation at Site ST-27 to further delineate the extent of mobile LNAPL on the groundwater table. Four additional shallow groundwater monitoring wells (MW20-9 through MW20-12) were installed and sampled from May through June 1993. The locations of these four wells are shown on Figure 1.3. Split-spoon samplers were used to collect continuous soil samples to the groundwater table, and a minimum of one sample from below the groundwater table in each of the four soil borings. The headspace of the soil samples was screened in the field for organic hydrocarbon vapors. One soil sample from each soil boring was submitted for laboratory analysis of volatile organic compounds (VOCs), semivolatile organic

compounds (SVOCs), total petroleum hydrocarbons (TPH) as gasoline and jet fuel, total lead, and toxicity-characteristic-leaching-procedure (TCLP) metals. The four new monitoring wells were gauged twice and sampled once during the investigation. EA (1993) detected minor quantities of mobile LNAPL in wells MW20-1 (0.10 foot) and MW20-5 (0.05 foot) during their investigation.

ES (1993) performed preliminary bioventing field tests at Site ST-27 in May 1993, under a separate AFCEE-sponsored effort. Initial testing procedures included a soil/air permeability test and *in situ* microbial respiration tests to determine if the site was suitable for application of the bioventing technology. A soil gas survey was conducted to identify areas where the subsurface soils were oxygen depleted and had elevated fuel hydrocarbon concentrations. Based on the soil gas survey results, one soil venting well (VW-1) and four permanent soil vapor monitoring points (MPA, MPB, MPC, and BG1) were installed to perform the initial pilot testing. Several soil samples were collected from the unsaturated zone and analyzed for total recoverable petroleum hydrocarbons (TRPH), BTEX, nutrients, pH, and other physical parameters. ES (1993) collected three soil gas samples from the vapor monitoring points (VMPs) for analysis of BTEX and total volatile hydrocarbons (TVH). Additionally, portable field instruments were used to measure soil gas composition of oxygen, carbon dioxide, and TVH during the soil gas survey and at the VMPs. Further discussion of the contaminant treatability pilot test results for bioventing and SVE is presented in Section 8. Figure 1.3 shows the relative locations and configuration of the VW-1 and VMPs used for the bioventing test.

1.3.2.2 Adjacent SWMUs

Prior to 1994, no integrity inspections and/or environmental sampling had been performed at any of the Building 575 SWMUs other than SWMU 145 (Site ST-27). HNUS (1994) conducted a field investigation of these SWMUs in April 1994 to determine the presence or absence of chemical contamination. This investigation was conducted as part of the Base-wide RFI, and consisted of visual site inspections and sampling and analysis of soil and groundwater. One additional shallow groundwater monitoring well (MW20-13) was installed approximately 30 feet downgradient from existing well MW20-4. The location of well MW20-13 is shown on Figure 1.3. This new well, and existing wells MW20-4 and MW20-12, were sampled as part of the RFI. Continuous soil samples were collected from three soil borings installed in expansion joints or other visible openings and cracks in the concrete of the aircraft washrack (SWMU 20). The results of this recent investigation are incorporated into this CAP (see Section 6 and Appendix B).

1.3.2.3 Site-Specific Risk Assessment

A risk assessment was prepared for Site ST-27 using available analytical data (Versar, Inc., 1992) and the US Environmental Protection Agency (USEPA, 1989) *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Part A.* The only exposure routes evaluated in the risk assessment were absorption of contaminants as a result of dermal contact with surface water and sediments that hypothetically could become impacted by contaminated groundwater. Receptor exposure pathways via surface water and sediments were presumed to be potentially complete by assuming that contaminated site groundwater could migrate to and

eventually impact the two main tributaries of Golf Course Creek, which are located 1,500 and 3,000 feet from Site ST-27. Although a series of drainage ditches could conceivably channel precipitation runoff or intercepted shallow groundwater to this surface water body, the nearest drainage ditch is more than 500 feet from the locations of the USTs and Building 575 at Site ST-27. No quantitative fate and transport analysis was completed to reasonably determine whether site-related contamination could ever migrate to and discharge into local surface water at hazardous concentrations. Instead, concentrations of specific compounds measured in surface water and sediment samples collected from Golf Course Creek in 1985 were used to estimate exposure-point concentrations. Interestingly, the compounds detected in 1985 in Golf Course Creek surface water and sediments (and used in the 1992 risk assessment) are dissimilar to those detected in soils and groundwater at Site ST-27 during the previous (GEL, 1988) and all subsequent investigations (EA, 1993; ES, 1993; HNUS, 1994 and 1995; the 1995/1996 risk-based investigation), which suggests that chemical contamination in these non-contiguous media is not related to chemical contamination associated with Site ST-27. Although the Versar, Inc. (1992) risk assessment concluded that no significant carcinogenic or noncarcinogenic health threat was associated with dermal exposure to 1985 chemical concentrations detected in surface water or sediments, the significant uncertainties related to subsurface contaminant fate and transport and the potential for increased risks over time prompted additional evaluation of Site ST-27.

Consequently, the focused site investigation and Tier 1/Tier 2 evaluation described in this CAP were designed to evaluate the type, magnitude, and timing of corrective action necessary to protect human health and the environment at and downgradient from Site ST-27 (and adjacent SWMUs). This CAP specifically documents the observed and predicted effects of natural physical, chemical, and biological processes and low-cost source reduction technologies on contaminant persistence, mobility, mass, and toxicity at Site ST-27 over time. The COPCs in affected site media were identified during the Tier 1 analysis (see Section 4). Particular emphasis is given to completing a quantitative exposure pathways analysis for these COPCs using analytical fate and transport models and reasonable land use assumptions (see Sections 5 and 6). The results of this evaluation are then used to develop appropriate and achievable Tier 2 SSTLs for Site ST-27.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

Since 1988, several soil and groundwater investigations have been conducted at Site ST-27 by various Air Force contractors. The earlier investigations focused on characterizing and delineating dissolved hydrocarbons in groundwater and, to a lesser extent, fuel hydrocarbons in soils. Parsons ES conducted a comprehensive site investigation at Site ST-27 from July 1995 through January 1996. The purpose of the Parsons ES field investigation was to completely define the vertical and horizontal extent of fuel hydrocarbons in soils and groundwater, and to collect site-specific data relevant to quantifying the effects of natural contaminant attenuation processes. Data gaps identified from previous investigations were addressed by Parsons ES as part of the risk-based field investigation. Additionally, potential impacts on Site ST-27 from adjacent SMWUs associated with the former aircraft washrack and oil/water separator drain system also were investigated.

To validate and implement a risk-based remedial approach at Site ST-27, additional data were collected by Parsons ES to: (1) establish groundwater flow characteristics, groundwater and soil geochemistry, and aquifer parameters; (2) identify all possible sources that may be contributing to groundwater contamination at the site; (3) evaluate the potential for contaminant source areas to degrade groundwater quality; and (4) identify potential contaminant receptors. Sufficient data were collected to conduct a quantitative fate and transport analysis, to perform an exposure pathways analysis, and to evaluate the potential treatability of contaminated media using low-cost remedial technologies and approaches. To the extent practicable, data previously collected by other contractors were used to augment this study and to facilitate the field investigation. In filling the data gaps from previous investigations, emphasis was placed on characterizing the nature and extent of source area soil contamination and on collecting data documenting the natural biodegradation and attenuation of fuel hydrocarbons in soils and groundwater at the site.

2.1 SCOPE OF DATA COLLECTION ACTIVITIES

As part of the risk-based remedial approach for Site ST-27, field data collection efforts focused on investigating specific chemical constituents that potentially pose a risk to human health and the environment. The chemicals targeted for study at this site were identified from previous site investigations and the chemical composition of the primary contaminant source (i.e., release(s) of JP-8 and JP-4 jet fuel from a former UST system). MOGAS also was stored at this site and also is considered a contaminant source. Additionally, chemicals that may have originated from secondary source areas at the adjacent washrack and oil/water separator drain system SWMUs were addressed

in this investigation. Several chemicals, specifically halogenated compounds, from potential sources other than jet fuel were detected in groundwater at this site during previous investigations. Regardless of these potential secondary sources, releases of JP-4 jet fuel and MOGAS are believed to be the predominant sources of contaminants at Site ST-27.

Aircraft jet fuel consists predominantly of C_5 through C_{14} hydrocarbons. The major hydrocarbon groups in JP-4 jet fuel (and their relative percentages by weight) are: n-alkanes (32 percent), branched alkanes (31 percent), cycloalkanes (16 percent), benzenes and alkylbenzenes (18 percent), and naphthalenes (3 percent). Major hydrocarbon groups in MOGAS are: n-alkanes (15 to 17 percent), branched alkanes (28 to 36 percent), cycloalkanes (3 to 5 percent), benzenes and alkylbenzenes (20 to 49 percent), naphthalenes (1 percent or less), and olefins (1 to 11 percent) (Arthur D. Little, 1987).

The fuel-derived chemicals identified and addressed as part of this study include the BTEX compounds, 1,2,4- and 1,3,5-trimethylbenzene (TMB), naphthalene, and chlorobenzene. These compounds were targeted based on the environmental fate of various hydrocarbons, previous site assessment results, and SCDHEC (1995) regulatory analytical requirements for petroleum UST sites. Additionally, analyses were performed for various SVOCs and other polynuclear aromatic hydrocarbons (PAHs) to determine the concentrations of these compounds in soils and groundwater at the site. Generally, analytical methods used previously during RI/FS studies and methods approved under the Charleston AFB Comprehensive RFI Work Plan (HNUS, 1993) were used during the risk-based field investigation. Analyses for halogenated organic compounds were conducted on most of the groundwater samples to determine if chlorinated compounds from nonfuel sources have impacted this site. A fixed-base laboratory (Evergreen Analytical, Inc. in Wheat Ridge, Colorado) provided analyses for these compounds in soil and groundwater samples. Field analyses and measurements were performed for various inorganic, geochemical, and physical parameters to document natural biodegradation processes and to assess the potential effectiveness of low-cost source reduction technologies.

The risk-based remediation investigation for Site ST-27 was conducted according to the methodologies presented in the *Final Draft Work Plan For An Engineering Evaluation/Cost Analysis To Support The Risk-Based Approach to Remediation at Site ST-27* (Parsons ES, 1994), hereafter referred to as the work plan. The work plan originally was developed according to available guidelines and minimum requirements to support an application for a "mixing zone" variance for groundwater in the State of South Carolina (SCDHEC, 1994). The data collected also are adequate to meet the requirements of the more recent and applicable state guidance for a risk-based tiered approach for petroleum release sites (SCDHEC, 1995). The following sampling and testing activities were performed by Parsons ES from July 1995 through January 1996 at Site ST-27 as part of this investigation:

- Installation of nine additional groundwater monitoring wells (MW20-14 through MW20-21, including two wells screened at different depths at MW20-18), one air sparging test well (ASW-1), and eight new shallow VMPs (MP-1 through MP-8).

- Collection of 30 subsurface soil samples for laboratory analyses from 15 of the boreholes drilled for the installation of new monitoring wells, the air sparging well, and VMPs (laboratory analytical samples were not collected from 3 of the 18 soil borings).

- Collection of 30 groundwater samples from a total of 22 groundwater monitoring wells, including 13 previously installed wells and the 9 new monitoring wells installed by Parsons ES.

- Collection of three SUMMA® canister soil gas samples for quantitative laboratory analyses from three soil VMPs located in close proximity to the suspected fuel source area.

- Collection of two samples of "free-phase," mobile LNAPL fuel product from wells MW20-1 and MW20-5 for laboratory analyses of fuel composition.

- Using portable field instruments, measurement of soil gas parameters of oxygen (O_2), carbon dioxide (CO_2), and TVH from six of the eight new VMPs (two of the VMPs contained water on the date of the field measurements).

- Performance of aquifer slug tests on 10 wells to determine the hydraulic conductivity of shallow and deep zones of the surficial (water table) aquifer.

In addition to these recent field activities, ES (1993) previously conducted a bioventing pilot test at Site ST-27 in May 1993. Field testing, sampling and data collection activities performed during the bioventing study that are relevant to this risk-based remediation study include the following:

- Performance of a limited soil gas survey using seven temporary VMPs to determine soil gas composition for O_2, CO_2, and TVH.

- Installation of four permanent VMPs (including a background point) and one vertical air injection VW (VW-1).

- Collection of three subsurface soil samples for laboratory analyses from boreholes installed for the VMPs and VW-1.

- Collection of three SUMMA® canister soil gas samples from three different VMPs for fixed-base laboratory analyses.

- Using portable field instruments, measurement of baseline soil gas parameters of O_2, CO_2, and TVH from the four VMPs and the VW.

- Performance of soil air permeability tests and initial *in situ* biorespiration tests.

Previous investigations at this site by other contractors included installation and sampling of 13 monitoring wells and collection of 9 subsurface soil samples for laboratory analyses. A free product fuel analysis and aquifer slug tests were also performed during prior investigations.

Figure 2.1 depicts the soil gas sampling locations at Site ST-27, including those temporary and permanent VMPs sampled for quantitative (laboratory) and semi-quantitative (field) analyses. Figure 2.2 shows the subsurface soil sampling locations at this site. Groundwater sampling locations are depicted in Figure 2.3, which presents all existing groundwater monitoring wells at the site. Figure 2.4 shows the mobile LNAPL fuel sampling locations.

Analytical method detection limit (MDL) requirements were considered before site characterization work was initiated under the risk-based remediation investigation. Suitable analytical methods and quality control (QC) procedures were selected (Parsons ES, 1994) to ensure that the data collected under this program are of sufficient quality to be used in a quantitative risk assessment.

Table 2.1 summarizes the analytical methods used for the different types of environmental samples collected under this program. This table also lists the laboratory-specified MDLs and practical quantitation limits (PQLs) for each analytical method by analyte and environmental sample matrix. The MDL is the lowest concentration at which a particular chemical can be measured and distinguished with 99-percent confidence from the normal "noise" of an analytical instrument or method. The PQL is the lowest level at which a chemical can be accurately and reproducibly quantitated.

Table 2.2 summarizes the field and fixed-base laboratory analyses used at each sampling location. Field sampling and testing activities performed during the risk-based remediation investigation are summarized in the following sections.

2.2 SOIL GAS MEASUREMENTS

Soil gas sampling was performed at Site ST-27 using both field (semi-quantitative) and laboratory (quantitative) analyses. The purpose of soil gas sampling was to better define the extent of contaminated soil and subsurface areas that have been impacted by fuel-contaminated vapors. Three soil gas samples were collected in SUMMA® canisters by ES in May 1993 as part of the bioventing pilot test. These samples were collected from VMPs MPA and MPC and from the VW (Figure 2.1). Three additional SUMMA® canister soil gas samples were collected from MP-3, MP-4, and MP-5 (Figure 2.1) in 1995 to further characterize soil gas conditions in the source area as part of the risk-based remediation study. For each sampling event, the soil gas samples were analyzed using USEPA Method TO-3 for TVH and BTEX compounds by Air Toxics, Ltd. in Folsom, California.

Prior to performing the bioventing test in 1993, a limited soil gas survey was conducted to field screen soil gas composition and to facilitate placement of the pilot test VW and VMPs. Soil gas samples were collected at seven locations using a

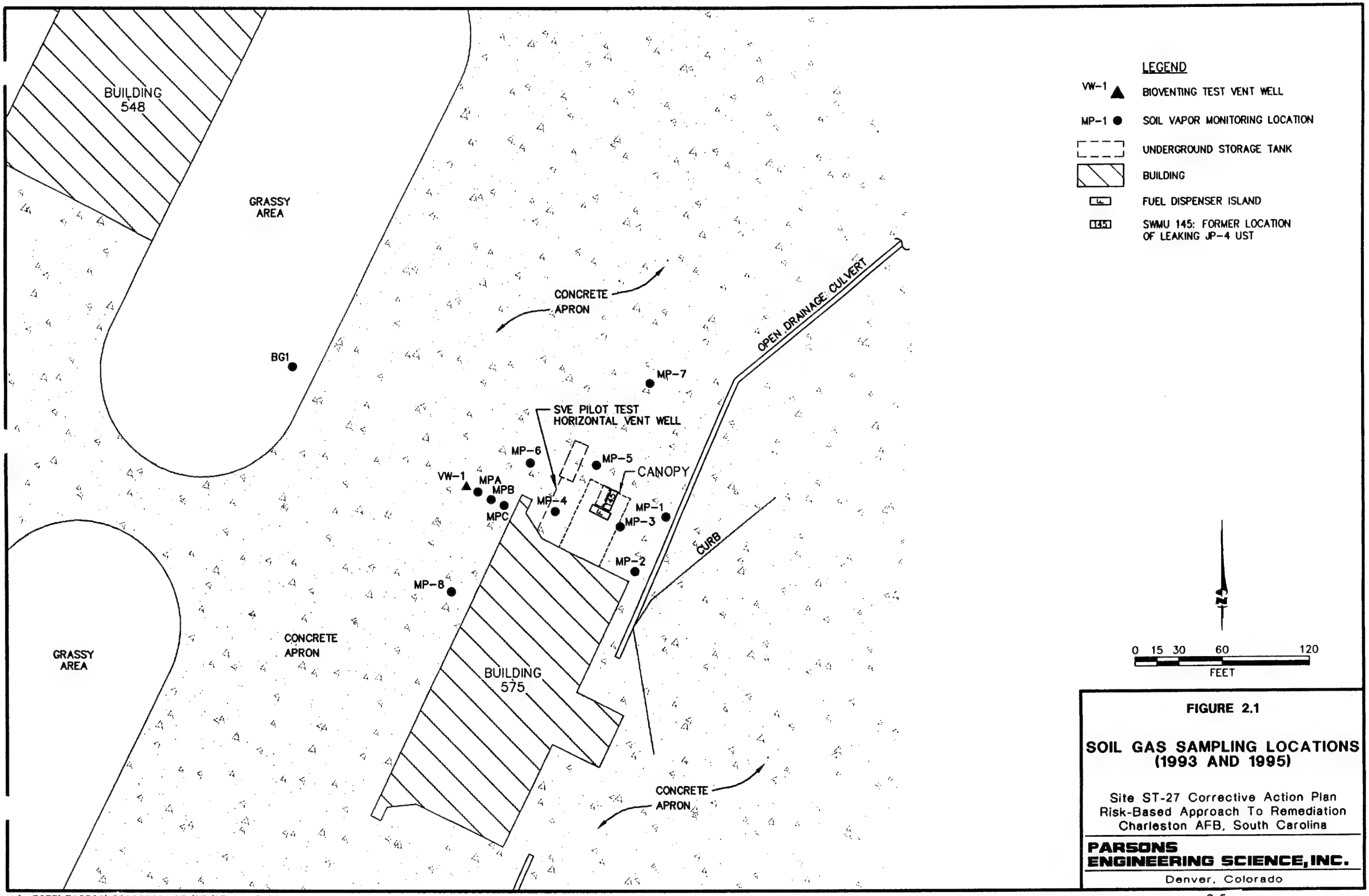

FIGURE 2.1

SOIL GAS SAMPLING LOCATIONS (1993 AND 1995)

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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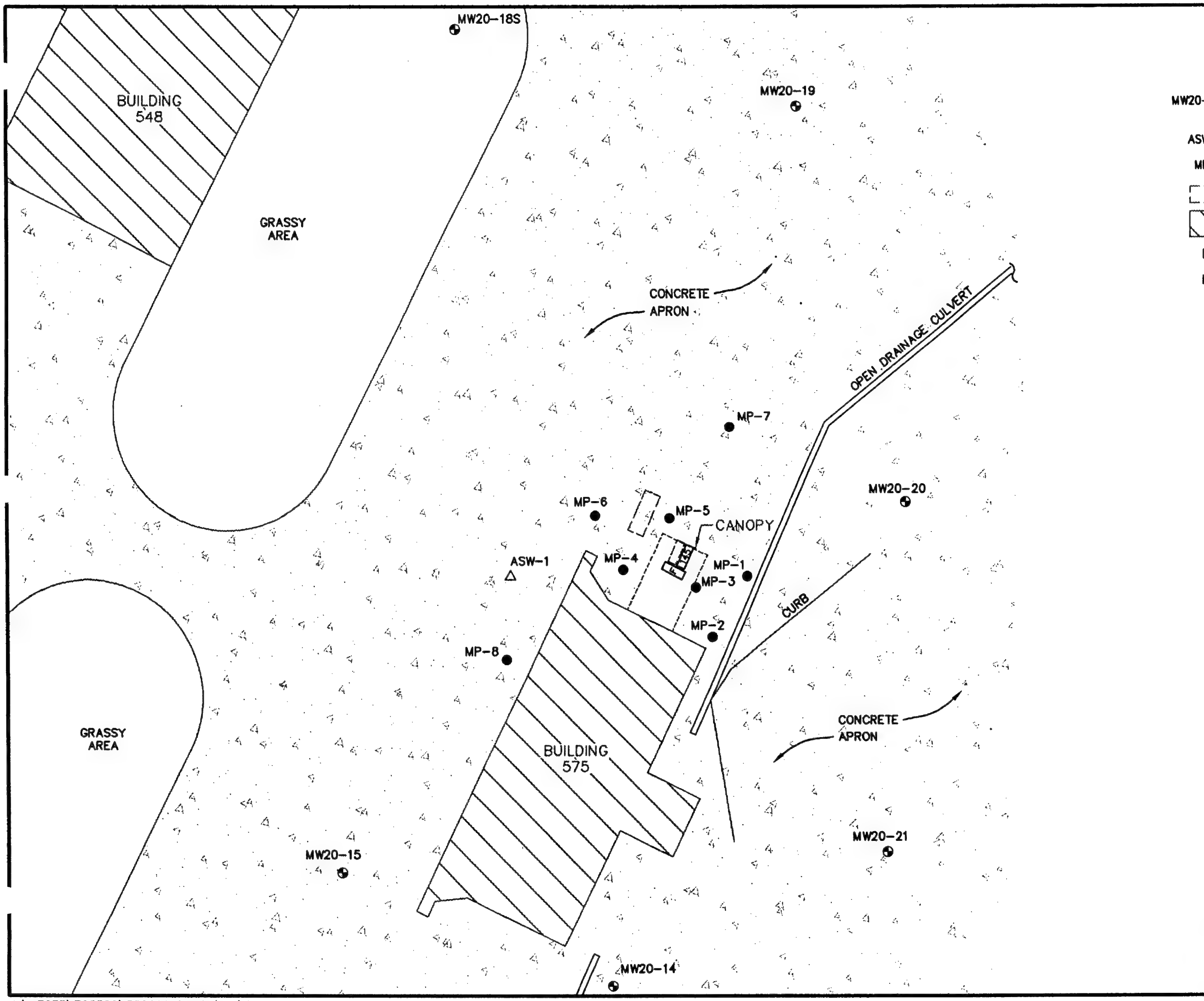

FIGURE 2.2

SOIL SAMPLING LOCATIONS (1995)

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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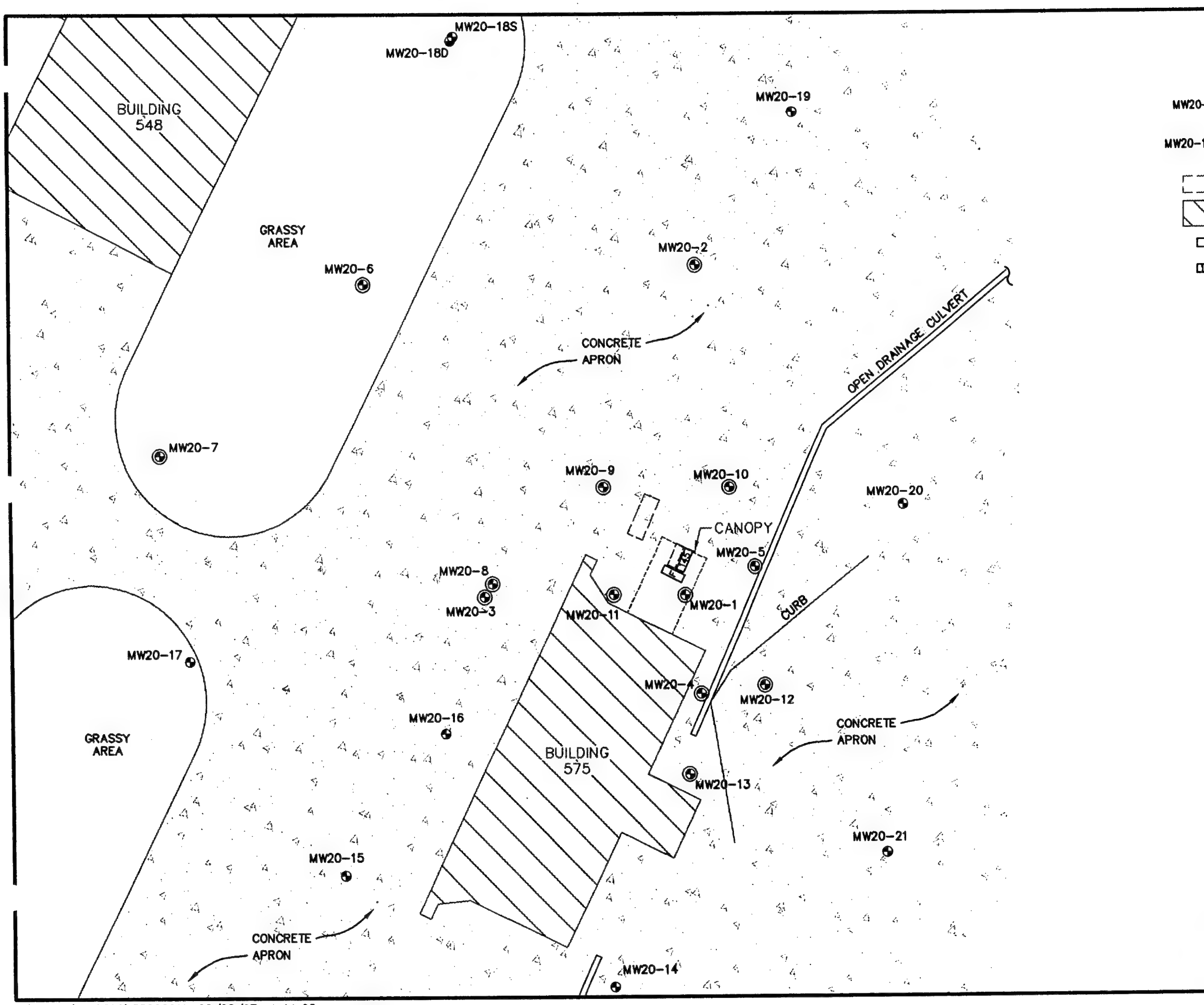

FIGURE 2.3

GROUNDWATER SAMPLING LOCATIONS (1995)

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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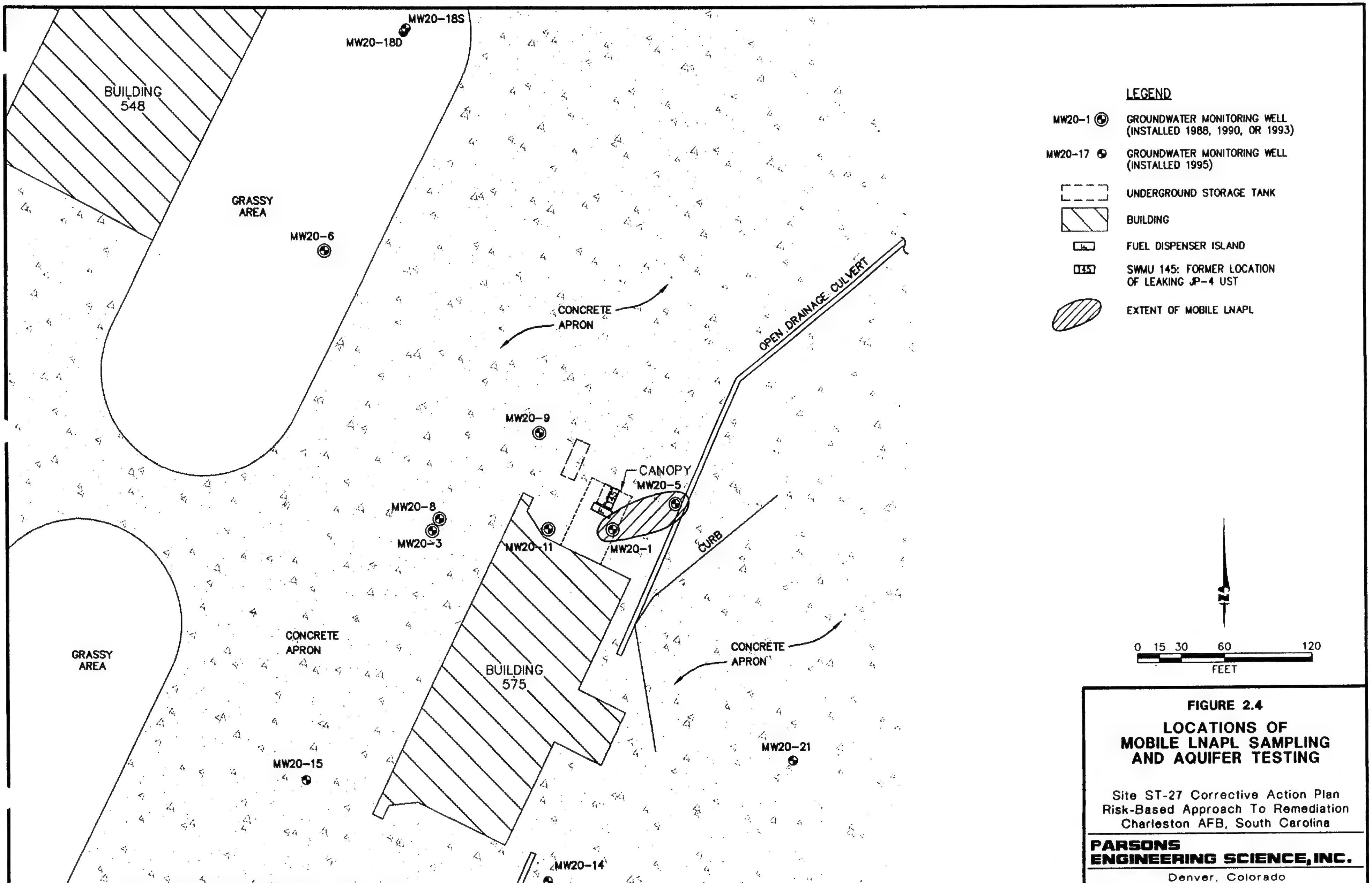

FIGURE 2.4

LOCATIONS OF MOBILE LNAPL SAMPLING AND AQUIFER TESTING

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 2.1
ANALYTE REPORTING LIMITS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil Reporting Limit[a]	Soil Units	Site-Specific Water MDL	Water Reporting Limit[a]	Water Units
SOIL GAS										
Benzene	TO3	Fixed-Base	0.001	ppmv						
Toluene	TO3	Fixed-Base	0.001	ppmv						
Ethylbenzene	TO3	Fixed-Base	0.001	ppmv						
Xylene (Total)	TO3	Fixed-Base	0.001	ppmv						
Total Volatile Hydrocarbons (TVH)	TO3	Fixed-Base	0.01	ppmv						
SOIL AND GROUNDWATER										
TEH as Jet Fuel	M8015	Fixed-Base				10	mg/kg	0.522	500	µg/L
TVH as Gasoline	M8015	Fixed-Base			0.006	0.1	mg/kg	0.089	100	µg/L
Benzene	SW8020/E602	Fixed-Base			0.283	0.4	µg/kg	0.283	0.4	µg/L
Toluene	SW8020/E602	Fixed-Base			0.257	0.4	µg/kg	0.257	0.4	µg/L
Ethylbenzene	SW8020/E602	Fixed-Base			0.283	0.4	µg/kg	0.283	0.4	µg/L
Xylene (Total)	SW8020/E602	Fixed-Base			0.247	0.4	µg/kg	0.247	0.4	µg/L
Chlorobenzene	SW8020/E602	Fixed-Base			0.283	0.4	µg/kg	0.283	0.4	µg/L
1,2,3,4-Tetramethylbenzene	SW8020/E602	Fixed-Base				0.5	µg/kg		0.5	µg/L
1,2,3-Trimethylbenzene	SW8020/E602	Fixed-Base			0.153	0.4	µg/kg	0.153	0.4	µg/L
1,2,4-Trimethylbenzene	SW8020/E602	Fixed-Base			0.168	0.4	µg/kg	0.168	0.4	µg/L
1,3,5-Trimethylbenzene	SW8020/E602	Fixed-Base			0.168	0.4	µg/kg	0.168	0.4	µg/L
Acenaphthene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Acenaphthylene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Anthracene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzo(a)anthracene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzo(a)pyrene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzo(b)fluoranthene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzo(g,h,i)perylene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzo(k)fluoranthene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Benzoic Acid	SW8270	Fixed-Base			10	330	µg/kg	10	50	µg/L
Benzyl Alcohol	SW8270	Fixed-Base			5	330	µg/kg	5	10	µg/L
bis(2-Chloroethoxy)methane	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
bis(2-Chloroethyl)ether	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
bis(2-Chloroisopropyl)ether	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
bis(2-Ethylhexyl)phthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
4-Bromophenyl-phenylether	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Butylbenzylphthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
4-Chloroaniline	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
4-Chloro-3-methylphenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
2-Chloronaphthalene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
2-Chlorophenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
4-Chlorophenyl-phenylether	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
Chrysene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Dibenz(a,h)anthracene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Dibenzofuran	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
1,2-Dichlorobenzene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
1,3-Dichlorobenzene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
1,4-Dichlorobenzene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
3,3'-Dichlorobenzidine	SW8270	Fixed-Base			2	330	µg/kg	2	20	µg/L
2,4-Dichlorophenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
Diethylphthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
2,4-Dimethylphenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
Dimethylphthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Di-n-butylphthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Di-n-octylphthalate	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
4,6-Dinitro-2-methylphenol	SW8270	Fixed-Base			10	330	µg/kg	10	50	µg/L
2,4-Dinitrophenol	SW8270	Fixed-Base			10	330	µg/kg	10	50	µg/L
2,4-Dinitrotoluene	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
2,6-Dinitrotoluene	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
Fluoranthene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Fluorene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Hexachlorobenzene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Hexachlorobutadiene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Hexachlorocyclopentadiene	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
Hexachloroethane	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Indeno(1,2,3-cd)pyrene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Isophorone	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
2-Methylnaphthalene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
2-Methylphenol(o-Cresol)	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
4-Methylphenol(p-Cresol)	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
Naphthalene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
2-Nitroaniline	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
3-Nitroaniline	SW8270	Fixed-Base			4	330	µg/kg	4	10	µg/L
4-Nitroaniline	SW8270	Fixed-Base			2	330	µg/kg	2	50	µg/L
Nitrobenzene	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
2-Nitrophenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L

TABLE 2.1
ANALYTE REPORTING LIMITS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil Reporting Limit a/	Soil Units	Site-Specific Water MDL	Water Reporting Limit a/	Water Units
4-Nitrophenol	SW8270	Fixed-Base			5	330	µg/kg	5	50	µg/L
N-Nitroso-di-n-propylamine	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
N-Nitrosodiphenylamine	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Pentachlorophenol	SW8270	Fixed-Base			5	330	µg/kg	5	50	µg/L
Phenanthrene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
Phenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
Pyrene	SW8270	Fixed-Base			0.5	330	µg/kg	0.5	10	µg/L
1,2,4-Trichlorobenzene	SW8270	Fixed-Base			1	330	µg/kg	1	10	µg/L
2,4,5-Trichlorophenol	SW8270	Fixed-Base			10	330	µg/kg	10	10	µg/L
2,4,6-Trichlorophenol	SW8270	Fixed-Base			2	330	µg/kg	2	10	µg/L
SOIL ONLY										
Nitrogen, Total Kjeldahl	E351.2	Fixed-Base				6	mg/kg			
pH	SW9045	Fixed-Base				0.01	pH units			
Total Organic Carbon	SW9060	Fixed-Base				0.05	%			
GROUNDWATER ONLY										
Benzene	SW8240	Fixed-Base						0.5	5	µg/L
Toluene	SW8240	Fixed-Base						0.5	5	µg/L
Ethylbenzene	SW8240	Fixed-Base						0.5	5	µg/L
Xylene (Total)	SW8240	Fixed-Base						0.5	5	µg/L
Chlorobenzene	SW8240	Fixed-Base						1	5	µg/L
Styrene	SW8240	Fixed-Base						1	5	µg/L
1,2,3,4-Tetramethylbenzene	SW8240	Fixed-Base							5	µg/L
1,2,3-Trimethylbenzene	SW8240	Fixed-Base							5	µg/L
1,2,4-Trimethylbenzene	SW8240	Fixed-Base							5	µg/L
1,3,5-Trimethylbenzene	SW8240	Fixed-Base							5	µg/L
Chloromethane	SW8260	Fixed-Base						1	10	µg/L
Bromomethane	SW8260	Fixed-Base						1	10	µg/L
Vinyl Chloride	SW8260	Fixed-Base						1	10	µg/L
Chloroethane	SW8260	Fixed-Base						1	10	µg/L
Methylene Chloride	SW8260	Fixed-Base						1	5	µg/L
Acetone	SW8260	Fixed-Base						10	100	µg/L
Carbon Disulfide	SW8260	Fixed-Base						1	5	µg/L
1,1-Dichloroethene	SW8260	Fixed-Base						1	5	µg/L
1,1-Dichloroethane	SW8260	Fixed-Base						1	5	µg/L
trans-1,2-Dichloroethene	SW8260	Fixed-Base						1	5	µg/L
cis-1,2-Dichloroethene	SW8260	Fixed-Base						1	5	µg/L
Chloroform	SW8260	Fixed-Base						0.5	5	µg/L
1,2-Dichloroethane	SW8260	Fixed-Base						1	5	µg/L
2-Butanone	SW8260	Fixed-Base						0.5	100	µg/L
1,1,1-Trichloroethane	SW8260	Fixed-Base						0.5	5	µg/L
Carbon Tetrachloride	SW8260	Fixed-Base						2	5	µg/L
Bromodichloromethane	SW8260	Fixed-Base						1	5	µg/L
Vinyl Acetate	SW8260	Fixed-Base						10	50	µg/L
1,2-Dichloropropane	SW8260	Fixed-Base						1	5	µg/L
trans-1,3-Dichloropropene	SW8260	Fixed-Base						1	5	µg/L
Trichloroethene	SW8260	Fixed-Base						1	5	µg/L
1,1,2-Trichloroethane	SW8260	Fixed-Base						1	5	µg/L
Benzene	SW8260	Fixed-Base						0.5	5	µg/L
Dibromochloromethane	SW8260	Fixed-Base						1	5	µg/L
cis-1,3-Dichloropropene	SW8260	Fixed-Base						2	5	µg/L
2-Chloroethylvinyl Ether	SW8260	Fixed-Base						5	10	µg/L
Bromoform	SW8260	Fixed-Base						1	5	µg/L
4-Methyl-2-Petanone	SW8260	Fixed-Base						5	50	µg/L
2-Hexanone	SW8260	Fixed-Base						5	50	µg/L
1,1,2,2-Tetrachloroethane	SW8260	Fixed-Base						1	5	µg/L
Tetrachloroethene	SW8260	Fixed-Base						1	5	µg/L
Toluene	SW8260	Fixed-Base						0.5	5	µg/L
Clorobenzene	SW8260	Fixed-Base						1	5	µg/L
Ethylbenzene	SW8260	Fixed-Base						0.5	5	µg/L
Styrene	SW8260	Fixed-Base						1	5	µg/L
Total Xylenes	SW8260	Fixed-Base						0.5	5	µg/L
Carbon Tetrachloride	SW8010	Fixed-Base						0.4	0.4	µg/L
Chloroethane	SW8010	Fixed-Base						0.6	0.6	µg/L
2-Chlorotoluene	SW8010	Fixed-Base						0.6	0.6	µg/L
4-Chlorotoluene	SW8010	Fixed-Base						0.5	0.5	µg/L
1,2-Dichlorobenzene	SW8010	Fixed-Base						0.4	0.4	µg/L
1,3-Dichlorobenzene	SW8010	Fixed-Base						0.5	0.5	µg/L
1,1-Dichloroethane	SW8010	Fixed-Base						0.5	0.5	µg/L
1,1-Dichloroethene	SW8010	Fixed-Base						0.8	0.8	µg/L
trans-1,2-Dichloroethene	SW8010	Fixed-Base						0.4	0.4	µg/L
cis-1,2-Dichloroethene	SW8010	Fixed-Base						0.4	0.4	µg/L
Methylene Chloride	SW8010	Fixed-Base						0.6	0.6	µg/L

TABLE 2.1
ANALYTE REPORTING LIMITS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil Reporting Limit[a]	Soil Units	Site-Specific Water MDL	Water Reporting Limit[a]	Water Units
Tetrachloroethene	SW8010	Fixed-Base						0.3	0.3	µg/L
1,1,1,2-Tetrachloroethane	SW8010	Fixed-Base						0.5	0.5	µg/L
1,1,2,2-Tetrachloroethane	SW8010	Fixed-Base						1.2	1.2	µg/L
Trichloroethene	SW8010	Fixed-Base						0.6	0.6	µg/L
1,1,1-Trichloroethane	SW8010	Fixed-Base						0.7	0.7	µg/L
1,1,2-Trichloroethane	SW8010	Fixed-Base						0.2	0.2	µg/L
Vinyl Chloride	SW8010	Fixed-Base						1.2	1.2	µg/L
Electrical Conductivity	FCOND	Field							0.02	mmhos/cm
Dissolved Oxygen	FDO	Field							0.5	mg/L
pH	FPH	Field							0.1	pH Units
Redox Potential	FREDOX	Field							0.01	pE Units
Temperature	FTEMP	Field							1	°C
Nitrate	H8039	Field						0.01	0.066	mg/L
Nitrite	H8040	Field						0.005	0.01	mg/L
Sulfate	H8051	Field						0.01	0.01	mg/L
Sulfide	H8131	Field						0.01	0.024	mg/L
Iron, Ferrous	H8146	Field						0.01	0.024	mg/L
Alkalinity (as $CaCO_3$)	H8221	Field						20	20	mg/L
Carbon Dioxide	H8223	Field						0.01	1.25	mg/L
Manganese	HMANG	Field						0.01	0.05	mg/L
Specific Conductance	E120.1	Fixed-Base							0.1	umhos/cm
Chloride	E300.0	Fixed-Base							0.25	mg/L
Nitrate	E300.0	Fixed-Base							0.056	mg/L
Nitrite	E300.0	Fixed-Base							0.076	mg/L
Alkalinity	E310.1	Fixed-Base							5	mg/L
Carbon Dioxide	COU-O2	Fixed-Base							5	mg/L
Methane	RSK175	Fixed-Base						0.004	0.004	mg/L
Ethane	RSK175	Fixed-Base						0.08	0.08	mg/L
Ethene	RSK175	Fixed-Base						0.11	0.11	mg/L

[a] Most of these reporting limits are equal to the pratical quantitation limit (PQL);
In some cases, the reporting limit is equal to the reliable detection limit (RDL).

TABLE 2.2
SAMPLE ANALYSIS BY SAMPLING LOCATION
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Sampling Location	Northing	Easting	Sample Matrix	Sample Depth (ft. bgs)	Analytes[a/]									
					BTEX	BNA	Halogenated VOCs	TVH/ TEH	Electron Receptors	ALK	CO2	CH4	Soil pH	Soil TOC
ASW-1	390825.47	2291507.078	Soil	3 - 5	1[b/]			X						
ASW-1	390825.47	2291507.078	Soil	5 - 7	1			X						
MP-1	390825.4113	2291653.42	Soil	2 - 4	1	X		X						
MP-1	390825.4113	2291653.42	Soil	4 - 6	1	X		X						
MP-2	390788.9927	2291631.697	Soil	2 - 4	1	X		X						
MP-2	390788.9927	2291631.697	Soil	4 - 6	1	X		X						
MP-3	390818.9305	2291621.543	Soil	3 - 4	1	X		X						
MP-3	390818.9305	2291621.543	Soil	4 - 5	1	X		X						
MP-3	390818.9305	2291621.543	Soil	5 - 6	1	X		X						
MP-3	390818.9305	2291621.543	Soil Gas	NA	2[c/]			X						
MP-4	390829.2493	2291576.371	Soil	2 - 4	1	X		X						
MP-4	390829.2493	2291576.371	Soil	4 - 6	1	X		X						
MP-4	390829.2493	2291576.371	Soil Gas	NA	2			X						
MP-5	390860.4961	2291605.15	Soil	2 - 4	1	X		X						
MP-5	390860.4961	2291605.15	Soil	4 - 6	1	X		X						
MP-5	390860.4961	2291605.15	Soil Gas	NA	2			X						
MP-6	390862.0123	2291559.129	Soil	2 - 4	1	X		X						
MP-6	390862.0123	2291559.129	Soil	4 - 6	1	X		X						
MP-7	390916.1149	2291642.507	Soil	2 - 4	1			X						
MP-7	390916.1149	2291642.507	Soil	4 - 6	1			X						
MP-8	390775.5193	2291503.871	Soil	2 - 4	1			X						
MP-8	390775.5193	2291503.871	Soil	4 - 6	1			X						
MW20-1	390815.911	2291615.183	Free Product	NA	1	X	X							
MW20-1	390815.911	2291615.183	Groundwater	NA	3[d/]	X	X	X	X	X	X	X		
MW20-2 [e/]	391016.902	2291622.932	Groundwater	NA	3	X	X	X	X	X	X	X		
MW20-3	390815.197	2291489.887	Groundwater	NA	1	X	X		X	X	X	X		
MW20-4 [e/]	390755.899	2291624.62	Groundwater	NA	1	X	X	X	X	X	X	X		
MW20-5	390832.993	2291659.032	Free Product	NA	1	X	X							
MW20-5	390832.993	2291659.032	Groundwater	NA	1		X	X	X	X	X	X		
MW20-6	391005.763	2291415.546	Groundwater	NA	1				X	X	X	X		
MW20-7	390902.0224	2291286.981	Groundwater	NA	1				X	X	X			
MW20-8	390823.168	2291494.843	Groundwater	NA	1	X			X	X	X	X		
MW20-9	390881.621	2291564.592	Groundwater	NA	1	X	X		X	X	X	X		
MW20-10	390881.324	2291643.301	Groundwater	NA	1	X	X		X	X	X	X		
MW20-11	390816.2496	2291570.634	Groundwater	NA	1	X	X	X	X	X	X	X		
MW20-12 [e/]	390760.969	2291664.793	Groundwater	NA	1	X	X		X	X	X	X		
MW20-13	390706.166	2291616.959	Groundwater	NA	1	X	X	X	X	X	X	X		
MW20-14	390577.042	2291568.938	Soil	3 - 5									X	X
MW20-14	390577.042	2291568.938	Soil	7 - 9									X	X
MW20-14	390577.042	2291568.938	Groundwater	NA	3	X	X	X	X	X	X	X		
MW20-15	390645.741	2291401.078	Soil	6 - 8									X	X
MW20-15	390645.741	2291401.078	Groundwater	NA	1				X	X	X	X		
MW20-16	390731.851	2291464.706	Groundwater	NA	1	X	X		X	X	X	X		
MW20-17	390776.859	2291304.619	Groundwater	NA	1				X	X	X	X		
MW20-18D	391154.98	2291470.932	Groundwater	NA	1				X	X	X	X		
MW20-18S	391157.536	2291472.542	Soil	3 - 5									X	X
MW20-18S	391157.536	2291472.542	Soil	13 - 15									X	X
MW20-18S	391157.536	2291472.542	Groundwater	NA	1				X	X	X	X		
MW20-19	391110.57	2291684.523	Soil	6 - 8									X	X
MW20-19	391110.57	2291684.523	Groundwater	NA	1				X	X	X	X		
MW20-20	390870.16	2291752.224	Soil	3 - 5									X	X
MW20-20	390870.16	2291752.224	Soil	6 - 8									X	X
MW20-20	390870.16	2291752.224	Groundwater	NA	1		X		X	X	X	X		
MW20-21	390658.297	2291740.519	Soil	7 - 9									X	X
MW20-21	390658.297	2291740.519	Groundwater	NA	1		X		X	X	X	X		

[a/] Refer to Table 2.1 for analytical methods and reporting limits.
[b/] 1 = SW8020: Purgeable Aromatics.
[c/] 2 = TO3: Determination of Volatile Organic Compounds in Soil Gas.
[d/] 3 = SW8020: Purgeable Aromatics, Confirmed by SW8240.

retractable soil vapor probe advanced to depths of 2 and 3 feet below ground surface (bgs). Field instruments were used to measure O_2, CO_2, and TVH concentrations. All samples were field screened using the test equipment and methods specified for field soil gas surveys in the AFCEE protocol documents *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee *et al.*, 1992) and *Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for Bioventing: Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential* (Downey and Hall, 1994). In addition to the seven temporary soil gas sampling points, soil gas samples were collected to establish baseline O_2, CO_2, and TVH concentrations at the four permanent VMPs (MPA, MPB, MPC, and BG1) and the VW that were installed to conduct the test.

Eight additional, permanent soil VMPs (MP-1 through MP-8) were installed by Parsons ES in 1995 to further characterize the source area and the extent of soil vapor contamination (Figure 2.1). These VMPs were also field screened for O_2, CO_2, and TVH. Soil gas SUMMA® canister samples were collected from three of the new vapor monitoring points (MP-3, MP-4, and MP-5) and analyzed using USEPA Method TO-3 for BTEX and TVH. Table 2.2 identifies the field and laboratory sampling matrix for each soil gas sampling location. All sample handling and field quality assurance (QA)/QC procedures for soil gas are specified in Appendix A of the work plan (Parsons ES, 1994). Analytical results for soil gas samples are summarized in Section 5 and are presented in tabular form in Appendix A of this report.

2.3 SUBSURFACE SOIL SAMPLING

Three soil samples were collected by ES as part of the 1993 bioventing initiative. Additional subsurface soil samples also were collected in July 1995, to further characterize the nature and extent of soil contamination at Site ST-27. Soil samples for laboratory or field analysis were collected at regular intervals from all of the boreholes that were advanced for installation of the groundwater monitoring wells, air sparging test well, and VMPs. Several soil samples were collected from most of the shallow boreholes, both above and below the groundwater surface. A total of 30 soil samples (including replicates) from 15 new boreholes were submitted for laboratory analyses. Samples from all 18 new boreholes were described for lithology and were field screened for organic vapors using a photoionization detector (PID) and/or a field TVH meter. Figure 2.2 shows the soil sampling locations for this site.

Several methods were used to collect subsurface soil samples, based on the sampling location and laboratory analyses to be performed on each sample. Soil samples from all locations other than MP-3 were collected using a mobile drill rig advancing 2- or 3-inch-diameter split-spoon sampling barrels through hollow-stem augers (ASTM Methods D1586 and D3550). Soil boring MP-3 was advanced and sampled using hand-auger methods (ASTM Method D1452) because its location near the Building 575 fuel canopy (Figure 2.2) was inaccessible to the mobile drill rig. Samples that were not submitted for laboratory analyses of specific target analytes and TPH were obtained using an unlined, 2-inch-diameter split-spoon barrel (ASTM Method D1586), with direct transfer of the samples into laboratory sample jars. Generally, these samples were collected from boreholes installed for new site-perimeter monitoring wells and

were analyzed for inorganic or noncontaminant parameters such as pH, total Kjeldahl nitrogen (TKN), and total organic carbon (TOC). Split-spoon barrels lined with four 6-inch-long brass sampling rings (ASTM Method D3550) were used to collect the soil samples that were submitted for specific analyte and TPH analyses. After recovering the sample, the brass rings were covered with Teflon® patches, capped, sealed air-tight, and labeled prior shipment to the laboratory. Compared to standard sampling methods, the sampling rings better preserve the integrity of the soil samples and minimize potential losses of VOCs that can occur during transfer of soil to sampling jars when sample ring liners are not used.

A total of 30 soil samples (including two replicate samples) were submitted to Evergreen Analytical, Inc. in Wheat Ridge, Colorado for laboratory analysis. Replicate samples were not collected for the nine soil samples that were analyzed only for TOC, pH, and TKN because these samples did not involve site-related or other regulated contaminants relevant to the risk evaluation for this site. Replicates were collected on a 10-percent sampling frequency (two samples) for the remaining 19 primary environmental samples that were collected for specific chemical analyses. Three trip blanks, two equipment rinseate blanks, and two field (ambient conditions) blanks were collected as part of the soil sampling QC program. Additionally, one decontamination water source blank was collected from the water storage tank on the steam cleaner. Table 2.2 presents the sampling matrix, sample intervals, and locations for all soil samples collected as part of the risk-based remediation study.

All boreholes advanced at the site were completed either as a well or shallow soil VMP. Soil boring logs, well completion diagrams, and survey data for all new sampling locations are included in Appendix B. The boring logs indicate the intervals where soil samples were collected for field headspace screening. Lithologic data are summarized in Section 3 to characterize the physical setting of the site. Soil analytical results are summarized in Sections 4 and 5.

2.4 GROUNDWATER SAMPLING

Nine new groundwater monitoring wells were installed by Parsons ES in July 1995, to monitor groundwater geochemical indicators and to delineate dissolved contaminants in groundwater at Site ST-27. One of the new wells (MW20-18D) was installed as a deep, double-cased well to monitor groundwater quality in the lower zone of the surficial aquifer. A total of 20 shallow and 2 deep groundwater monitoring wells and 1 air sparging test well now exist at Site ST-27. Well construction records and soil boring logs for the new wells and ASW-1 are found in Appendix B.

Groundwater samples were collected from all 22 groundwater monitoring wells at the site in August 1995. The groundwater samples were analyzed for fuel and nonfuel contaminants and for various inorganic and geochemical indicators to evaluate natural chemical and physical attenuation processes that are occurring at the site. Three confirmatory groundwater samples also were collected from three of the wells (MW20-2, MW20-4, and MW20-12) in January 1996 to further quantify the presence or absence of chlorinated solvent contamination in groundwater. Groundwater samples were collected using the procedures described in the work plan (Parsons ES, 1994).

These procedures are in accordance with the general protocols outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (USEPA, 1987). Two duplicates, two equipment blanks, two field (ambient conditions) blanks, six trip blanks, and one decontamination water source blank were collected during the groundwater sampling event.

Prior to sampling, the wells were gauged for static water levels and product thicknesses. The wells were then slowly purged using a low-flow peristaltic pump to minimize agitation of the water column. During the purging process, the indicator parameters of pH, dissolved oxygen (DO), temperature, reduction/oxidation (redox) potential, and conductivity were measured using portable field instruments. Field geochemical analyses were also performed for nitrate, ferrous iron, sulfate, sulfide, manganese, carbon dioxide, and alkalinity using field colorimetric test (Hach®) methods. These field tests and methods are specified in the draft AFCEE document *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater,* which was prepared by Parsons ES and the USEPA's National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division (Wiedemeier *et al.*, 1995). The groundwater geochemical data that were collected are used to assess the biodegradation potential of dissolved COPCs and to quantitatively document chemical fate and transport processes.

The 22 groundwater sampling locations (MW20-1 through MW20-21) are shown on Figure 2.3. Field and laboratory analytical data were collected at each groundwater sampling location, as summarized in Table 2.2. All groundwater samples collected in August 1995, including QA/QC samples, were analyzed for BTEX compounds by USEPA Method SW8020. Additionally, all but one of the samples were analyzed for the TMB isomers, 1,2,3,4-tetramethylbenzene, and chlorobenzene using USEPA Method SW8020. USEPA Method SW8270 was used to quantify semivolatile PAH compounds in groundwater at 11 of the sampling locations. Groundwater samples were analyzed by USEPA Method SW8010 (halogenated volatile organics) from 14 sampling locations to determine the presence of chlorinated compounds that may have originated from SWMUs or other potential sources adjacent to Site ST-27. Additional QA/QC verification was provided by analyzing three samples by USEPA Method SW8240 to obtain second-column, mass spectrometer confirmation of the VOCs. In addition to the compound-specific analyses, seven groundwater samples were analyzed for total volatile petroleum hydrocarbons (TVPH) as gasoline and total extractable petroleum hydrocarbons (TEPH) as JP-4 jet fuel by USEPA Method 8015 (modified). The three samples collected in January 1996 were only analyzed for chlorinated compounds using mass spectrometer confirmation (USEPA Method SW8260).

Fixed-base laboratory analyses also were performed on many of the groundwater samples for indicators of natural attenuation chemical processes. These included analyses for methane, ethane, and ethene (RSKSOP Method 175), CO_2, nitrates/nitrites, chloride, alkalinity, and conductivity. Because many of these anion and inorganic analyses were duplicated for the samples using field test methods (Hach® kits), the fixed-base laboratory analyses provided some level of laboratory verification of and/or correlation with the field results.

Table 2.1 summarizes the types of field measurements completed as part of this investigation. Field and laboratory groundwater analytical results are discussed and depicted graphically in Section 5 of this report. These analytical results are used in Section 6 to evaluate the natural physical, chemical, and biological processes that are affecting the contaminants at this site.

2.5 MOBILE LNAPL SAMPLING

Samples of mobile LNAPL fuel (i.e., "free product") were collected and analyzed from two groundwater monitoring wells at Site ST-27 (see Figure 2.4). Mobile LNAPL was detected by Parsons ES in monitoring wells MW20-1 (0.15 foot) and MW20-5 (0.1 foot) during the initial well gauging and purging event beginning on August 7, 1995. The LNAPL fuel layers were bailed from the wells on that date to allow relatively "fresh" samples of product to enter the wells from the formation. Parsons ES returned to the site on August 23, 1995 to regauge all of the wells and to collect LNAPL samples from the two wells.

LNAPL fuel samples were collected using clear, disposable bailers lowered into the wells just below the fuel/water interface. The water phase collected in each bailer was drained off through a bottom sample tap until the remaining liquid in the bailer was predominantly fuel (oily phase). The fuel samples were then transferred to sample containers and shipped as flammable, hazardous goods to Evergreen Analytical, Inc. for analyses. The fuel samples were collected, handled, and transported according to the sampling protocols developed for environmental soil and water samples as specified in the work plan (Parsons ES, 1994). No field QA samples (i.e., duplicates, field blanks, or equipment blanks) were collected during the fuel sampling event.

Both fuel samples were analyzed for BTEX compounds, TMB isomers, tetramethylbenzene, and chlorobenzene by USEPA Method SW8020, SVOC and PAH compounds by USEPA Method SW8270, and halogenated VOCs by USEPA Method SW8010. As LNAPL hydrocarbons potentially represent significant, long-term contaminant sources at fuel spill sites, these compound-specific analyses were used to determine the mass of fuel constituents that may contribute to fuel contaminants in the soils, groundwater, and soil gas at Site ST-27. The relative mass of LNAPL fuel remaining in the subsurface and its phase-partitioning properties are factors that will affect how effective any SCDHEC-required active product recovery efforts may be at reducing site contamination over time. Of particular interest to this study is the mass fraction of BTEX compounds remaining in the fuel that is available to partition into groundwater, as the BTEX compounds are among the most toxic and mobile chemicals in the fuel product. Laboratory results of the LNAPL sample analyses are discussed in Section 5. The laboratory results are used in Section 6 to evaluate the source contribution from the remaining LNAPL fuel.

2.6 AQUIFER TESTING

Parsons ES performed aquifer slug tests at 10 monitoring wells on November 13, 1995. Slug tests provide estimates of aquifer hydraulic conductivity, which is needed to complete the hydrogeologic evaluations and to support quantitative chemical fate and

transport analyses. Parsons ES used the aquifer testing methods and protocols described in Appendix A of the work plan (Parsons ES, 1994) to conduct the slug tests. Slug tests were performed on monitoring wells at various locations and depths to provide an adequate representation of aquifer hydraulic conditions throughout the site and at multiple depths of the groundwater contaminant plume.

Aquifer slug testing was conducted in two distinct test phases on each well. The initial test phase was conducted as a "falling head" test by quickly introducing a slug of known volume into the water column of the well and measuring the subsequent downward recovery of the water level to its equilibrium position. After the water level reached equilibrium, the slug was quickly removed from the well to perform the second step, or "rising head" portion of the test. After removing the slug, the "rising head" portion of the test was completed by measuring the upward recovery of the water level to its equilibrium position or until a minimum 90-percent recovery was achieved. The tests were conducted using decontaminated steel and polyvinyl chloride (PVC) slugs of known volume. Parsons ES utilized downwell pressure transducers connected to automatic data loggers (*In-Situ*, Inc. Hermit Model SC1000-C) to electronically measure and record the water level recovery data.

Data obtained from the slug tests were analyzed using the AQTESOLV software program (Geraghty & Miller Modeling Group, 1994). This program evaluates aquifer hydraulic conductivity based on the Hvorslev (1951) solution for confined aquifers, and the Bouwer and Rice (1976) solution for unconfined aquifers. The Bouwer and Rice method was used to obtain solutions for both the "falling head" (slug-in) and "rising head" (slug-out) portions of the tests. Results of the slug tests are discussed in Section 3 as part of the site hydrogeologic evaluation. The test data plots and results are summarized in Appendix C.

2.7 SOURCE-REDUCTION FEASIBILITY TESTING

Two potentially appropriate engineered source-reduction technologies have been identified for this site. These technologies include: 1) SVE to remove the high concentrations of fuel vapors accumulated beneath the site and to enhance biodegradation of fuel residuals in soils; and 2) shallow *in situ* bioventing to add oxygen to the capillary fringe "smear zone," and to promote *in situ* biodegradation. Additionally, a preliminary bioventing pilot test using air injection was conducted by ES at this site in May 1993. Figure 2.5 presents the locations of all pilot-scale treatability tests performed at Site ST-27.

An SVE pilot test utilizing a horizontal vapor recovery trench and an internal combustion engine (ICE) to treat vapor emissions was initiated in January 1996. The SVE test was run for several months to evaluate the feasibility of removing VOCs and reducing the contaminant mass in the source area using this technology. Based on the results of the initial test, a second horizontal vapor recovery trench was installed at the site in August 1996. Results of the initial SVE pilot testing at Site ST-27 are included in Section 8.

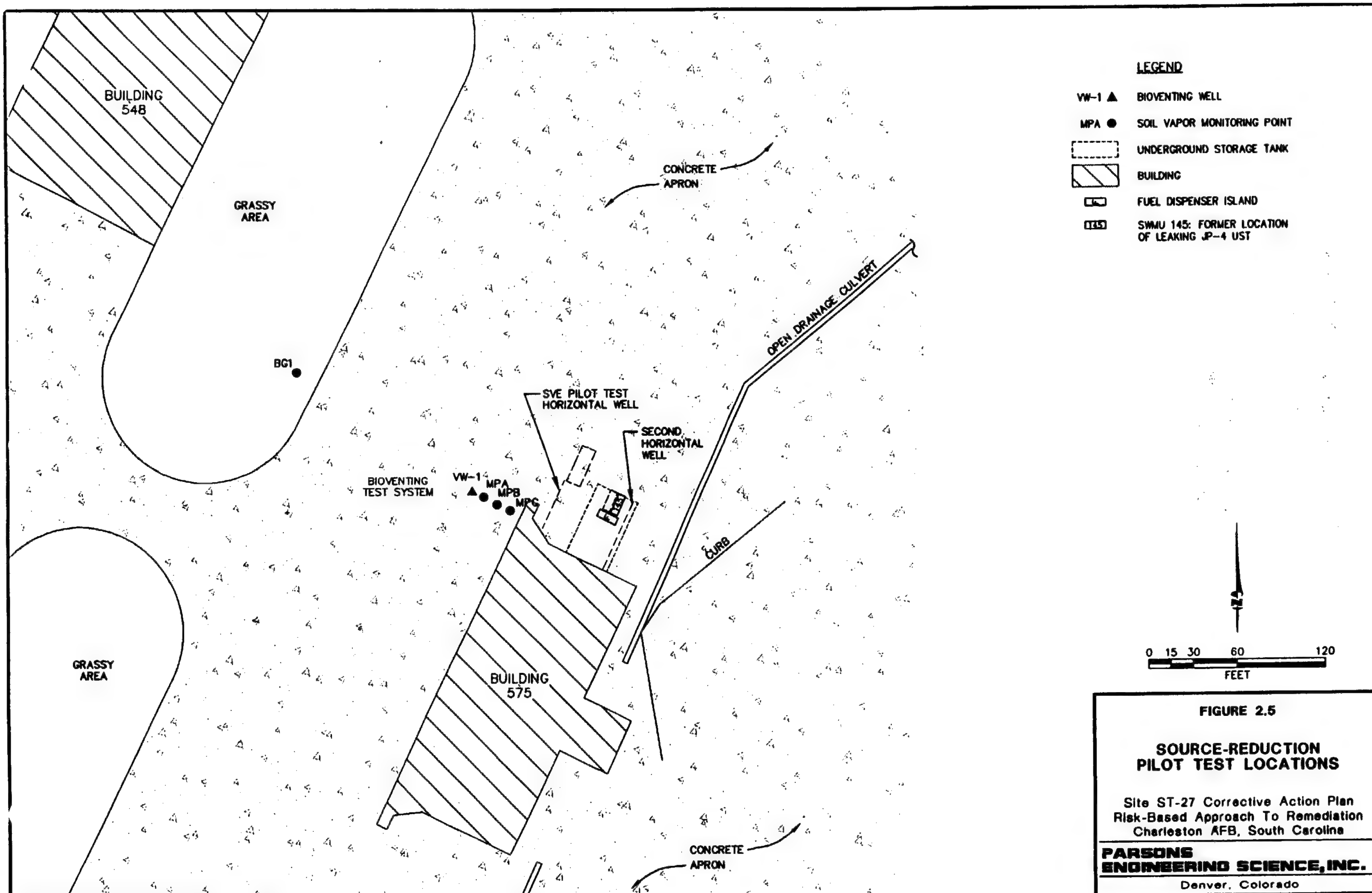

FIGURE 2.5

SOURCE-REDUCTION PILOT TEST LOCATIONS

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Charleston AFB, South Carolina

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Results of the May 1993 preliminary bioventing pilot test and its potential applicability to reduce COPCs at this site are discussed in Section 8. Final data from the bioventing pilot test are reported in the Interim Bioventing Pilot Test Results Letter Report (ES, 1993). *In situ* bioventing can be achieved by any engineered process that increases the oxygen concentrations in unsaturated soils in order to enhance or stimulate aerobic microbial biodegradation of organic compounds. As a result, it is anticipated that some degree of bioventing will be achieved during the SVE operations, as both of these technologies ventilate unsaturated zone soils.

2.8 ANALYTICAL DATA QUALITY AND MANAGEMENT

Analytical data collected during the 1995/1996 risk-based investigations were reviewed to ensure that they were suitable for use in risk analyses and met other project data quality objectives. Data management protocols followed during this CAP evaluation are summarized in this section.

All analytical results collected during the 1995/1996 risk-based remediation investigation were identified as not detected (U qualified) and reported by the analytical laboratory at the PQL when not detected at concentrations above the MDL (see Table 2.1). The MDL is defined as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero (USEPA, 1992). The MDL takes into account the reagents, sample matrix, and preparation steps applied to a sample in specific analytical methods (USEPA, 1989) (see Table 2.1).

During all risk analyses for Site ST-27, one-half the sample quantitation limits (SQLs) were selected to represent nondetected results. USEPA (1989) guidance states, "Most analytes at a site are not positively detected in each sample collected and analyzed. Instead, for a particular chemical the data set generally will contain some samples with positive results and others with non-detected results. The non-detected results usually are reported as SQLs." Sample-specific quantitation limits (as surrogate values at one-half the SQL for all nondetects) are used in the risk analysis (comparison of site data to risk-based concentrations, etc.) because they take into account sample characteristics (matrix effects), sample preparation, and analytical adjustments (dilutions). When Site ST-27 maximum site concentrations were compared to soil and groundwater RBSLs during the Tier 1 evaluation, unusual or "aberrantly" high SQLs were carefully evaluated prior to conducting a risk evaluation using these data. Unusual or aberrantly high SQLs may be due to unavoidable matrix interferences that resulted in analytical dilutions related to other target analytes within the method. Significantly inflated SQLs for nondetected values were eliminated from statistical data computations or calculations when the SQLs were found to be more than four times the maximum detected (i.e., actual positive result) value. This is consistent with USEPA (1989) guidance on the use of SQLs as surrogate values for nondetected results in quantitative risk analyses.

It is worth noting that SQLs in the risk analysis can be equal to or greater than the PQL/PRL. This is because the PQL/PRL is a predetermined maximum reporting limit that AFCEE and the contracted laboratory have agreed upon. The SQL is actually the

MDL adjusted to reflect sample-specific factors such as analytical dilution, or use of a smaller sample aliquot for analysis, due to matrix effects or the high concentration of some analytes. Therefore, there are instances when the SQL may greatly exceed the PQL/PRL, and one-half the SQL would serve as the appropriate "proxy" or surrogate concentration for the nondetected result. If the laboratory analysis did not require analytical adjustments to the sample or analysis, the SQL and PQL were the same for all nondetected target compounds.

All analytical results measured above the MDL but below the PQL were identified as quantitatively estimated (i.e., an analyte's presence was positively identified above zero), but usable, data (J qualified). All analytical results measured above the PQL were identified as detected concentrations (i.e., positive analytical results) and are quantitatively reliable, therefore qualification is not required. Detections above the PQL may, however, be qualified on the basis of other exceeded QC criteria.

Data also were subject to a usability/acceptability review that included (1) a review of chain-of-custody records, reported holding times, status of instrument calibration, and reported recoveries for laboratory control samples and matrix spike/matrix spike duplicates; (2) analyzing and using laboratory and field blanks to qualify reported sample concentrations; and (3) measuring the reproducibility of sampling techniques and laboratory analytical precision using blind field duplicates/replicates. Appendix A presents the analytical results for all samples collected under this project, organized by environmental medium, and a summary of the data quality evaluation results.

In summary, the data quality review identified no major or minor problem areas. All analyses were completed well within specified method holding times. The calculated relative percent differences (RPDs) for replicate analytical results for soils demonstrated an adequate level of reproducibility. The maximum soil RPD was 46.32 percent, although the majority of soil RPDs were below 20 percent. Additionally, the RPDs for duplicate analytical results for groundwater samples showed a high level of analytical reproducibility. Except for one sample where phenanthrene was detected in the primary sample at a concentration slightly above the MDL but not detected in the duplicate sample, all the RPDs for water samples were less than 25 percent. Phenanthrene is not identified as a groundwater COPC (see Section 4).

SECTION 3

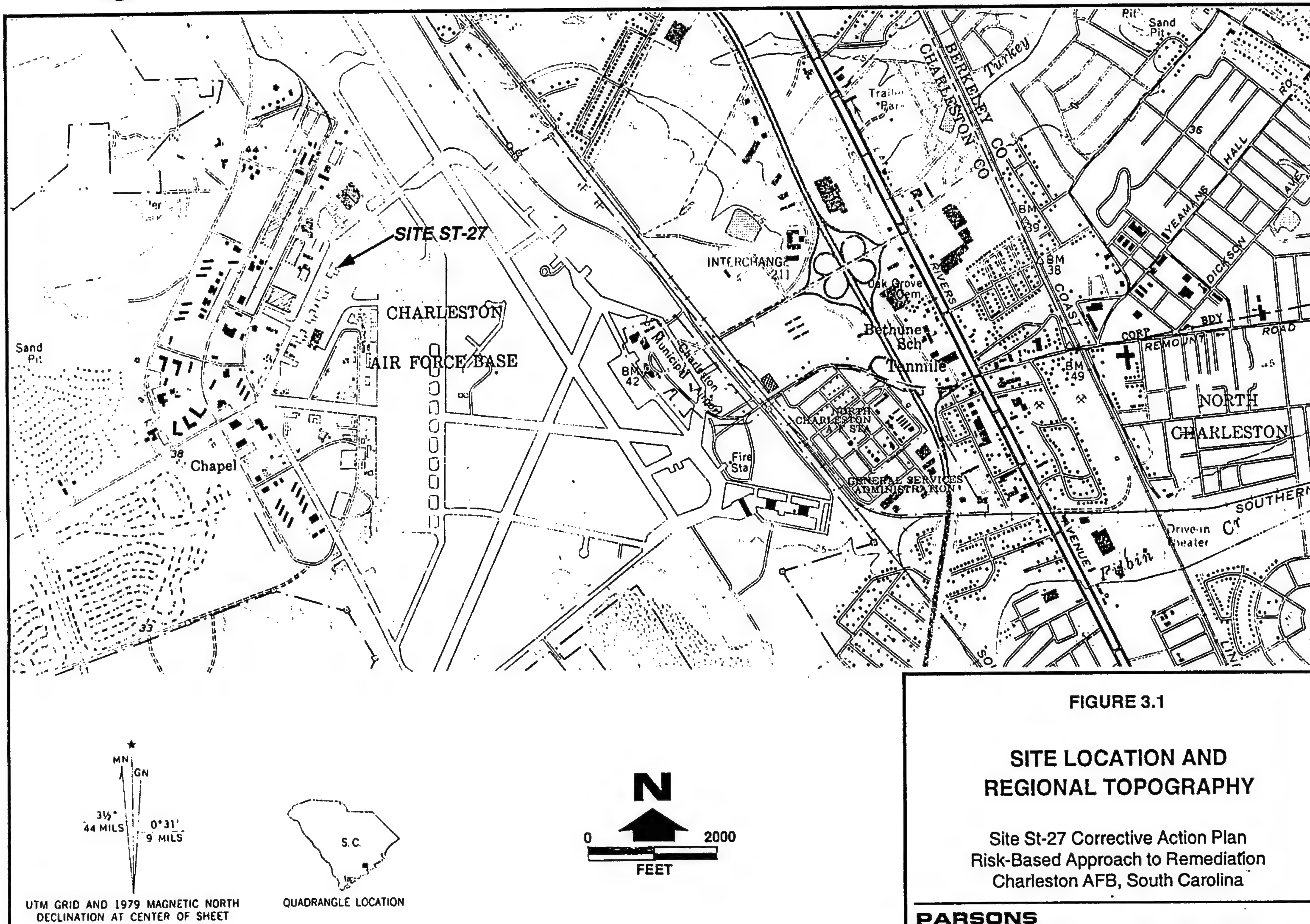
PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of Site ST-27 and adjacent environs at Charleston AFB, as determined from data collected during previous site investigations and from data collected by Parsons ES in July 1995 through January 1996 as part of the risk-based remediation field investigation. Data incorporated into this section are based on the results of earlier Base-wide and/or site-specific investigations (ES, 1983; GEL, 1988; Versar, Inc., 1991 and 1992; EA; 1993, HNUS, 1995), the bioventing pilot test (ES, 1993), and other relevant Base-wide planning documents. A summary of site characterization activities completed by Parsons ES to supplement existing data is presented in Section 2 of this CAP.

3.1 REGIONAL TOPOGRAPHY AND HYDROLOGY

Charleston AFB is located in the Lower Coastal Plain area of the Atlantic Coastal Plain physiographic province, approximately 16 miles northwest of Charleston Harbor and the Atlantic Ocean. Figure 3.1 shows the regional location of the Base on the US Geological Survey (USGS, 1958) Ladson Quadrangle topographic map. This area is characterized by a relatively flat topographic relief and abundant wetlands and marsh areas around creeks and other surface water bodies. On a regional scale, both surface drainage and shallow groundwater flow away from the low-relief interstream divides toward the creeks. Elevations at Charleston AFB range from a maximum of about 45 feet above mean sea level (msl) in the northwestern part of the Base, to a low of about 15 feet above msl on the extreme southeastern corner of the Base. The Base is relatively flat, and does not have any natural, steep slopes. However, some small, man-made, steep-slope areas have been constructed for embankments or drainage ditches.

Surface water drainage from approximately 3,500 acres of watershed in the vicinity of the Base is controlled by a series of unlined and concrete-lined ditches and buried conduits. The three primary surface drainages at the Base are: 1) Golf Course Creek, which flows west-southwest to Popperdam Creek, a tributary of the Ashley River; 2) Runway Creek near Runway 03/21 (the secondary, southwest-northeast runway); and 3) a tributary of Turkey Creek east of Runway 15/33 (the primary, northwest-southeast runway), which discharges to Goose Creek, a tributary of the Cooper River. The Base is located outside of the 100-year floodplain areas of the Ashley and Cooper Rivers; the closest 100-year floodplain boundary is about 1,200 feet off-Base and downstream from Golf Course Creek (ES, 1983).



Source: USGS, 1958.

FIGURE 3.1

SITE LOCATION AND REGIONAL TOPOGRAPHY

Site St-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

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A regional surface water drainage divide is located near the east-central part of the Base, approximately parallel to Runway 15/33 (Figure 3.1). Surface water east of Runway 15/33 flows east toward Goose Creek and the Cooper River, and surface water west of Runway 15/33 flows west toward Popperdam Creek and the Ashley River. Most of the secondary, unlined drainages are losing water courses, with drainage bottoms located above the water table. The larger surface water drainages such as Golf Course Creek and Runway Creek intersect the water table and are likely effluent, or gaining, streams (Versar, Inc., 1991). Other surface water bodies in the vicinity of Charleston AFB include Goose Creek Reservoir and several localized wetland areas. Goose Creek Reservoir, located approximately 2 miles northeast of the Base (Figure 1.2), is used as a major supply of potable water (Versar, Inc., 1992).

Twenty-five isolated and/or adjacent jurisdictional freshwater wetlands have been identified and located at Charleston AFB. The US Army Corps of Engineers has concurred with the jurisdictional wetlands determination (HNUS, 1993). The wetlands range in size from 0.276 to 93.193 acres, although only 6 wetlands are greater than 10 acres in size. The 25 wetlands cover a total of 282 acres at Charleston AFB, and consist primarily of seasonally and temporarily flooded palustrine forested wetlands.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.2.1 Geology

The regional geology of the Lower Coastal Plain physiographic province consists of a thick wedge of unconsolidated and partially consolidated sediments underlain by crystalline basement rock. These sediments are characterized as interbedded sands, silts, clays, and limestones deposited by fluvial and marine processes. The interbedded sedimentary layers are grouped into regional formations and aquifers based on lithologic and water quality characteristics. The regional sedimentary deposits, which thin inland toward the central part of South Carolina, are estimated to be 3,000 feet thick in the Charleston area (Versar, Inc., 1992).

Shallow sediments and geomorphic features in this region are associated with coastal plain terrace deposits. The thickness of these terrace deposits averages about 30 feet at the Base, and the deposits consist primarily of shells, sand, silt, and clay deposited during a series of marine transgressions and regressions. The Ladson Formation comprises the surficial, coastal terrace deposit in the vicinity of the Base. It consists of fine- to coarse-grained sands, silty sands, and clays, and locally contains the surficial water table aquifer. The aquifer and Ladson Formation are underlain by the relatively impermeable Cooper Formation, which is about 200 feet thick near the Base and forms a regionally extensive aquitard. The Cooper Formation is characterized by olive-green, phosphatic deposits, including calcareous sands, clays, and marls (Versar, Inc., 1992).

The Soil Conservation Service (SCS) completed a soils map of Charleston AFB in 1983. Fifteen different soil types were identified, all of which were either fine sand or sandy loam soils. Residual soils are sandy at the surface, and the clay content tends to increase with depth. Consequently, the infiltration capacity is relatively high (6 to 20

inches per hour) at the surface and relatively low (0.06 to 6 inches per hour) at depths of about 8 to 80 inches bgs (Versar, Inc., 1992).

3.2.2 Hydrogeology

The hydrogeology of the Lower Coastal Plain near Charleston AFB consists of an unconfined surficial aquifer, a confined Tertiary aquifer system, and a confined Cretaceous aquifer system (Colquhoun *et al.*, 1983). The surficial aquifer occurs within the Ladson Formation. The surficial aquifer is unconfined, laterally extensive, and approximately 20 to 30 feet thick near the Base. Depth to water in the surficial aquifer ranges from about 0.25 to 13 feet bgs, although the water table fluctuates seasonally about 1 to 6 feet per year. The general direction of groundwater flow within the surficial aquifer is to the south-southeast [Science Applications International Corporation (SAIC), 1989], although seasonal fluctuations can cause directional shifts. The horizontal groundwater flow rate in the surficial aquifer is about 13 to 234 feet per year (ft/yr) (HNUS, 1993). Recharge to the surficial aquifer occurs via infiltration of precipitation. The Cooper Formation acts as a thick confining unit between the surficial aquifer and the underlying aquifer systems. The lower aquifer systems are used to meet water supply demands in the area; but there is no effective communication between the Ladson Formation and deeper aquifers.

3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

Site ST-27 is located on the western edge of the Air Mobility Command (AMC) Maintenance Apron and near the Building 575 maintenance hangar (Figure 1.2). Adjacent SWMUs that are part of the Building 575 oil/water separation system are constructed on part of a northwestern taxiway to Runway 15/33. All taxiways except the east access taxiway are constructed of full-depth, Portland®-cement concrete. The surface elevation at Site ST-27 and adjacent SWMUs averages about 40 feet above msl. The site is relatively flat and is covered with 8 to 14 inches of reinforced concrete that completely surrounds Building 575. Surface drainage of the concrete pad around Building 575 is controlled by a series of storm drains and engineered surface drainage features. The concrete immediately surrounding Building 575 is gently sloped toward the open stormwater drain/sump (SWMU 22), which is located on the east and southeast sides of Building 575 (see Figure 1.3). This storm drain forms the western edge of the former aircraft washrack adjacent to Building 575, and receives runoff from both the washrack (SWMU 20) and much of the concrete pad and aircraft apron adjacent to Building 575. This drain discharges into the Base sanitary sewer. The nearest surface water drainage feature, a drainage ditch, is located approximately 750 feet northwest of the site along Graves Avenue (Figure 3.1).

3.4 SITE GEOLOGY AND HYDROGEOLOGY

The shallow subsurface stratigraphy at Site ST-27 has been established from numerous soil borings completed during previous IRP investigations and the 1995 risk-based investigation. Generally, shallow stratigraphy (i.e., 0 to 34 feet bgs) can be described as 8 to 14 inches of concrete overlying undifferentiated, moderately sorted sands and silty to clayey, fine to medium sands of the Ladson Formation. Underlying

the concrete layer are 3 to 5 feet of gray to pale-brown, silty fine to medium sand with a trace of clay. The upper 1 to 2 feet of this sand unit appear to be backfill and/or reworked residual soils at several locations. Beneath the upper silty sand unit is a pale yellow-brown clayey sand unit that is about 4 to 7.5 feet thick. The water table of the surficial aquifer tends to occur in this clayey sand unit, and its physical characteristics (i.e., higher clay content) suggest that it may be less permeable than the overlying silty sand unit. Underlying the clayey sand unit are approximately 25 feet of pale-gray to yellow-brown, silty, fine to medium sands. A plastic, low-permeability clay layer was encountered from 33.5 to 35 feet bgs in the soil boring for deep well MW20-8 (Versar, Inc., 1992). It is not known if this clay layer is laterally extensive or if it is associated with the basal, low-permeability sediments that define the lower extent of the Ladson Formation and the upper portions of the confining Cooper Formation. No soil borings that penetrate through this clay layer and into the Cooper Formation have been completed at the site.

Figures 3.2 and 3.3 are the north-south and east-west hydrogeologic cross-sections, respectively, for Site ST-27. The location of each cross-section is profiled on the figures for clarity. These hydrogeologic interpretations incorporate data from all field investigations that have been conducted at the site to date. Note that an interbedded clay layer was identified above the seasonal-high groundwater table during drilling of soil borings MW20-1 and MW20-5 (GEL, Inc., 1988). No distinguishable interbedded clay layer was logged during drilling of soil boring MW20-11 (EA, 1993), which is about 45 feet west of MW20-1 (Figure 1.4).

Groundwater at Site ST-27 is encountered at average depths ranging from about 4 to 6 feet bgs. Water level data from 1990 through 1993 indicate that the water table at this site can fluctuate from 1 to 3 feet on a seasonal basis. The maximum observed change in water table elevation was 3.15 feet at well 20-5 (Versar, Inc., 1992). Interpretation of historical water table elevation data indicates that the groundwater flow within the immediate vicinity of Site ST-27 can be highly variable, and even multi-directional. Available water table elevation data collected during nine gauging events (performed from 1988 through 1996) suggest that flow can occur in nearly any direction (Figure 3.4). However, the most consistent flow direction observed at Site ST-27 has been toward the southwest (July 1988, June 1990, July 1994, and August 1995). Groundwater elevation data from two additional gauging events (June 1993 and January 1996) suggest a slight mounding of groundwater immediately northeast of the location of former USTs that would cause groundwater near the source area to flow toward the southwest. The open drainage culvert (SWMU 22) east of Building 575 collects storm water from much of the surrounding tarmac during precipitation events. It is possible that storm water collected in the culvert is percolating through cracks and/or joints in the cement, infiltrating through unsaturated soils, and eventually discharging into underlying groundwater. Consequently, it is conceivable that the drainage culvert acts as a recharge area, which is sufficient to cause a slight local mounding of groundwater relative to the extremely low gradient observed across the site. A comprehensive, Base-wide water table surface map created from April 1994 gauging data shows regional groundwater flow directions toward the southeast, south, and southwest in the vicinity of Site ST-27 (HNUS, 1995).

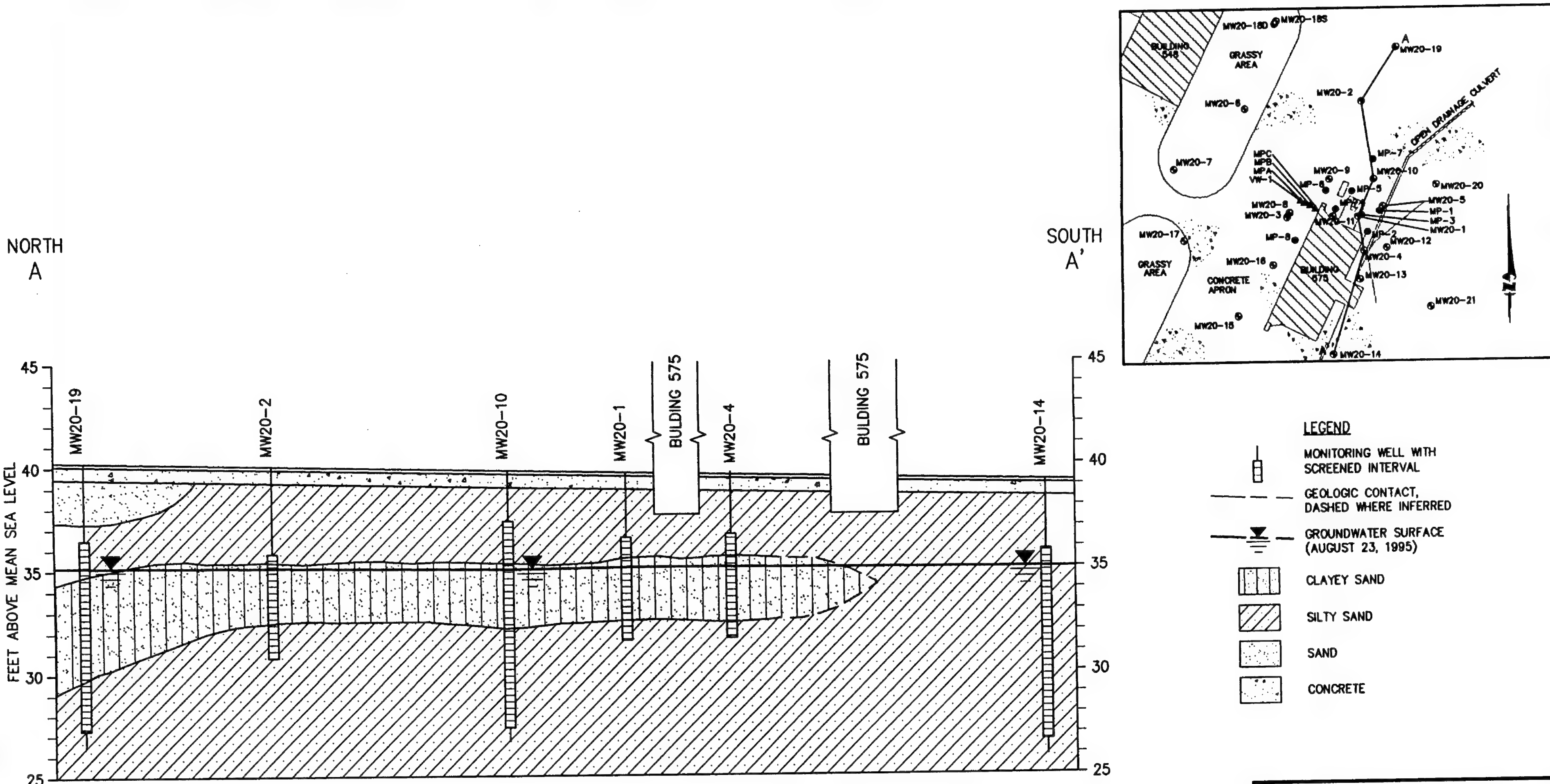

FIGURE 3.2

NORTH-SOUTH HYDROGEOLOGIC CROSS-SECTION

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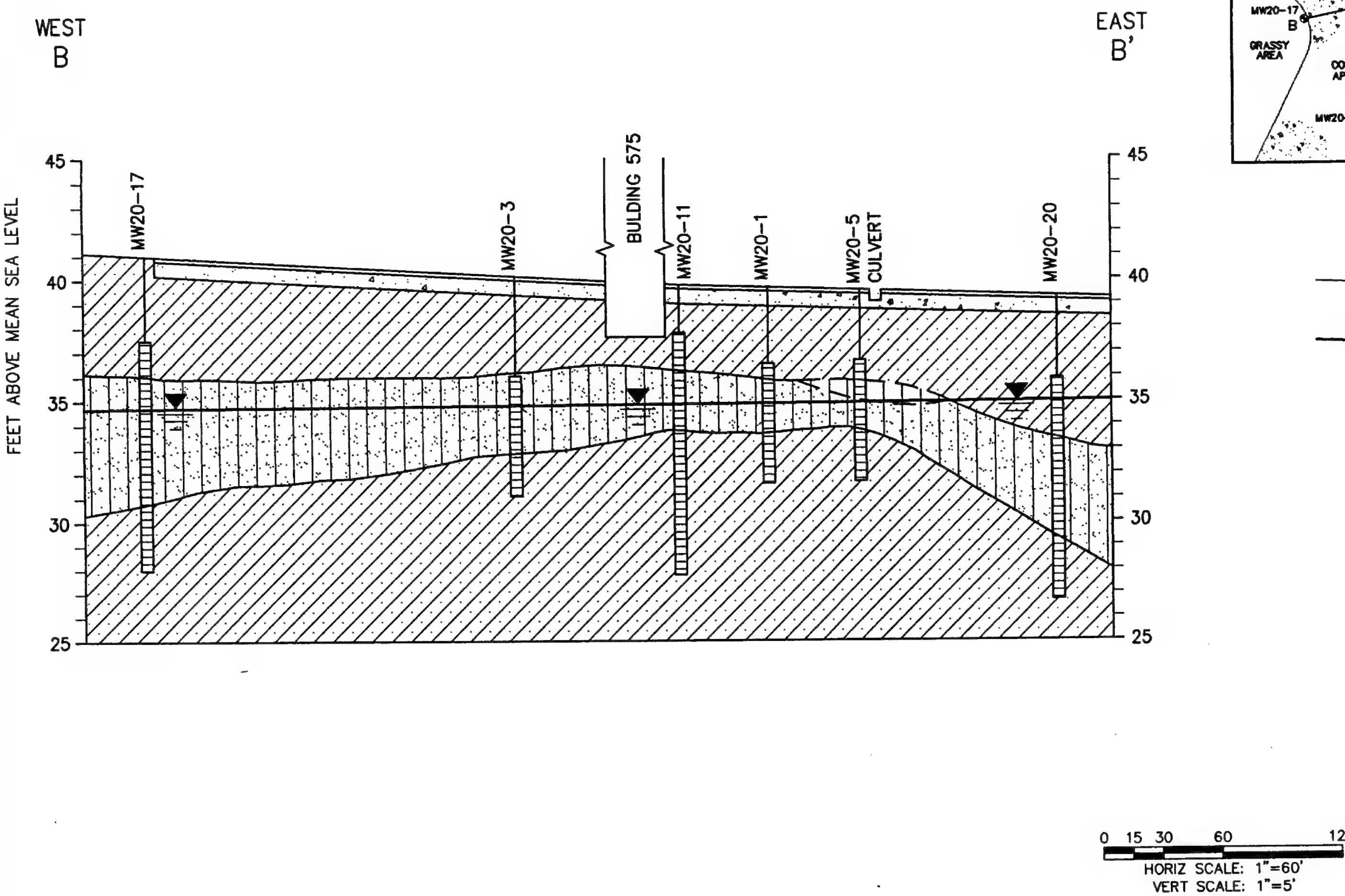

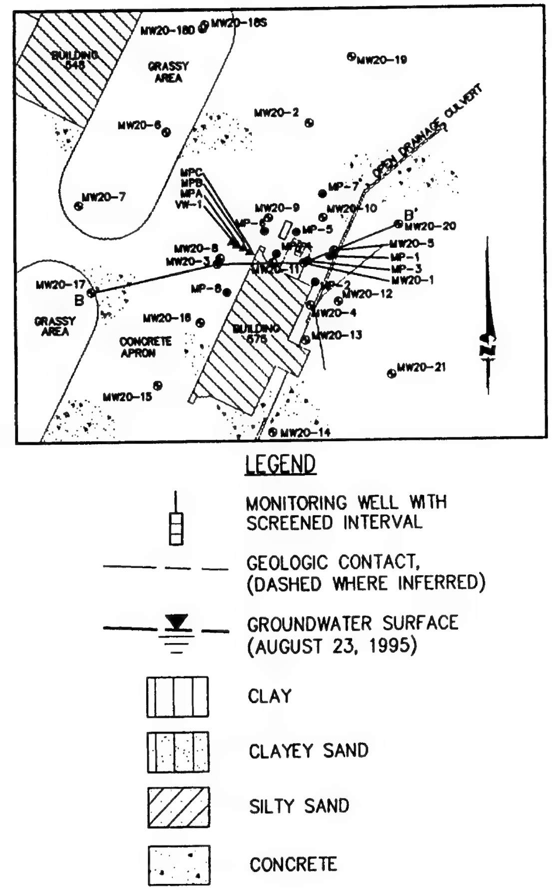

FIGURE 3.3

EAST-WEST HYDROGEOLOGIC CROSS-SECTION

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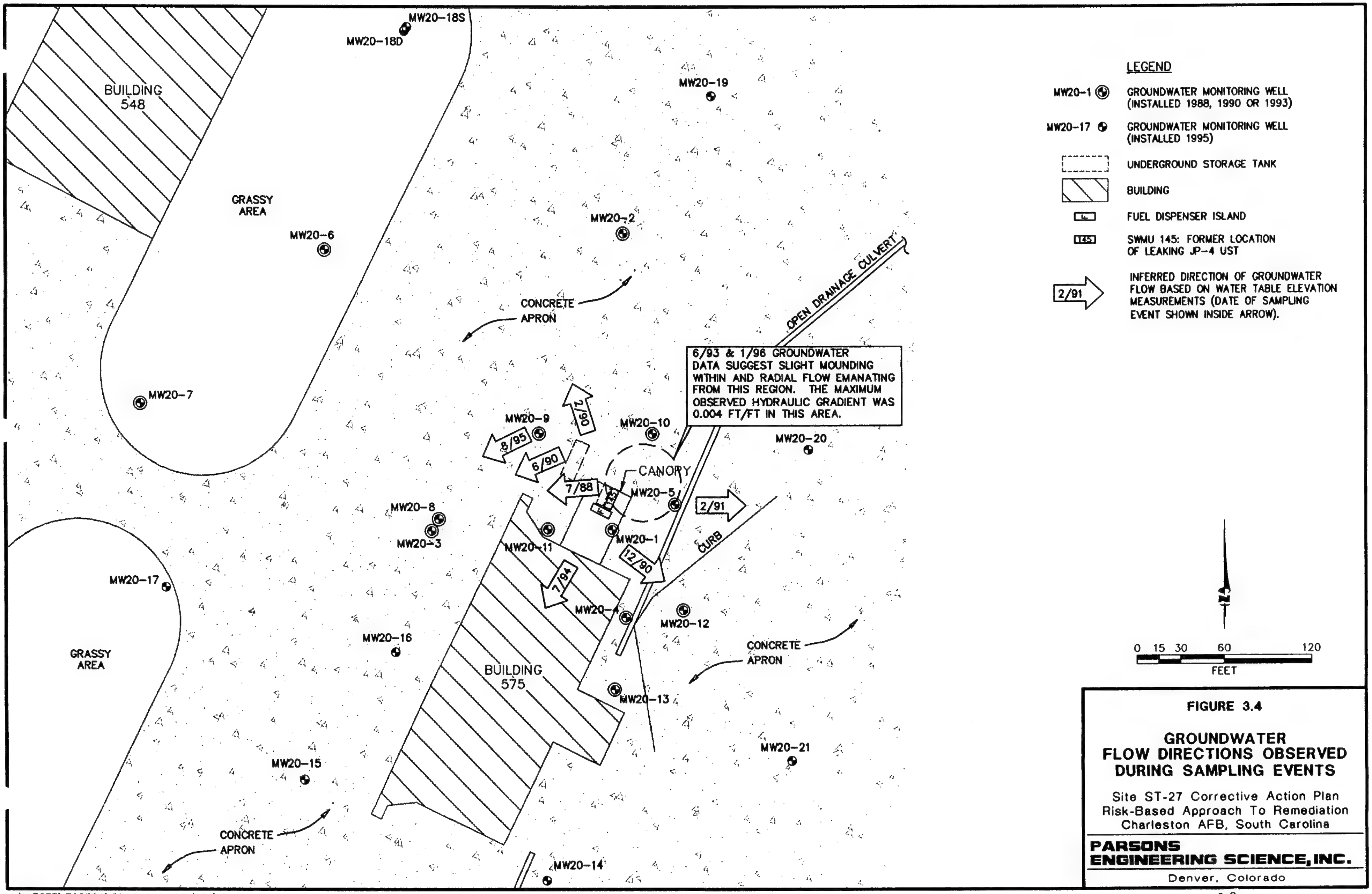

FIGURE 3.4

GROUNDWATER FLOW DIRECTIONS OBSERVED DURING SAMPLING EVENTS

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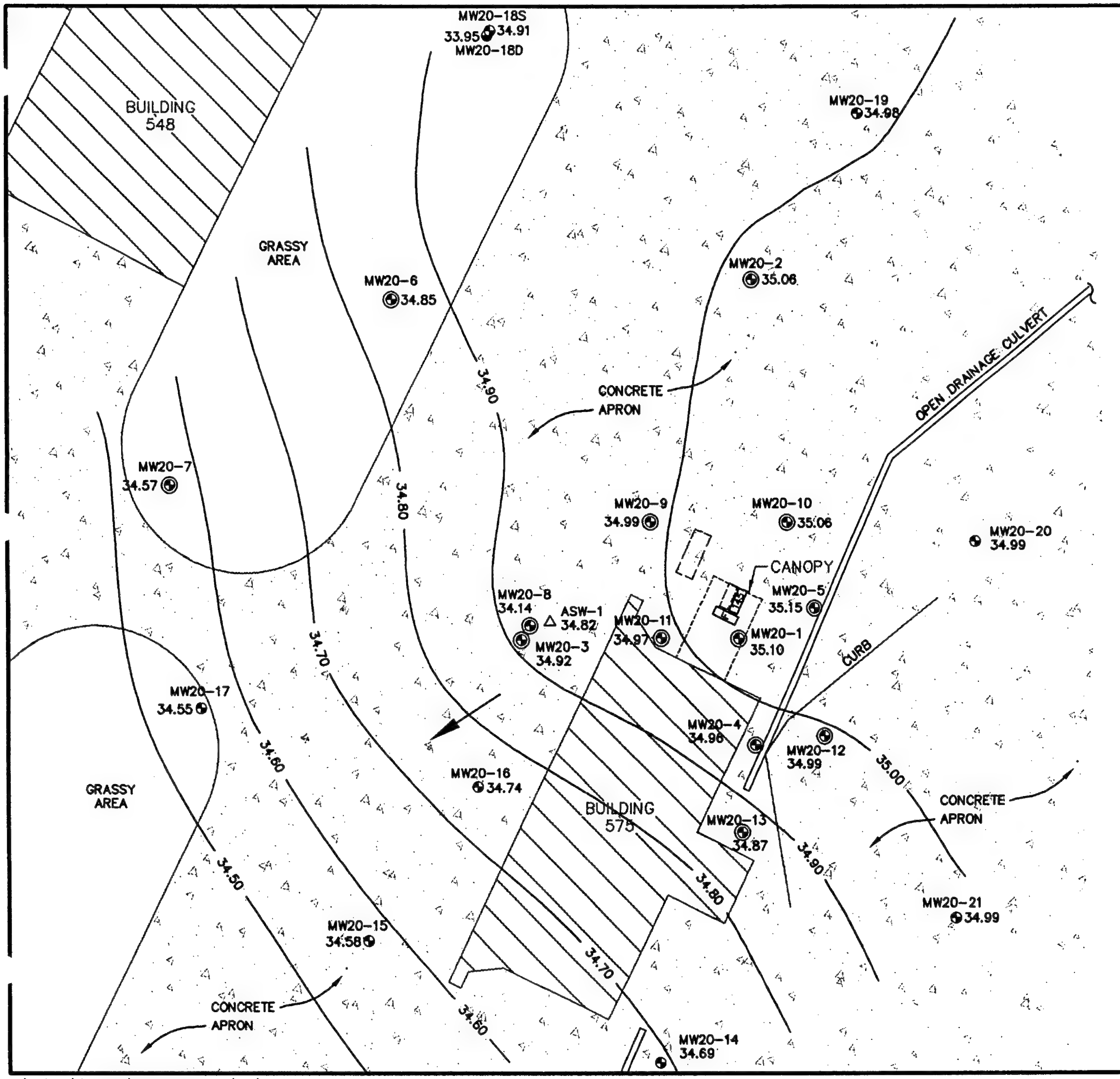
A water level/LNAPL gauging event was conducted on August 23, 1995 during the risk-based field investigation. These data were used to prepare the groundwater surface map presented in Figure 3.5. The observed horizontal gradient at the site is extremely low [0.0014 foot per foot (ft/ft)], particularly in the vicinity of the former UST at Site ST-27 and the adjacent SWMUs. Vertical gradients were observed at nested well MW20-18, which is screened in both the shallow (midpoint depth 8.2 ft bgs) and the deeper (midpoint depth 29.6 ft bgs) portions of the Ladson Formation, and the well pair MW20-3 and MW20-8, which are screened at 6.6 and 27.6 ft bgs, respectively. The vertical gradient observed near MW20-18 was 0.0445 ft/ft, downward, while the vertical gradient near the well pair (MW20-3 and MW20-8) was observed to be 0.0371 ft/ft, downward. These vertical gradients are an order of magnitude greater than the observed horizontal gradient.

Ten aquifer slug tests using groundwater monitoring wells MW20-3, MW20-6, MW20-8, MW20-9, MW20-11, MW20-14, MW20-15, MW20-18 (shallow and deep), and MW20-21 (Figure 2.3) were performed at Site ST-27 as part of the 1995 risk-based investigation to assess the hydrogeologic characteristics of the surficial aquifer. The test data yielded estimated hydraulic conductivities ranging from 1 x 10^{-4} to 5 x 10^{-3} foot per minute (ft/min) at wells screened across the upper few feet of the surficial aquifer. In comparison, lower hydraulic conductivities of 1 x 10^{-4} to 9 x 10^{-4} ft/min were observed at the monitoring wells screened across deeper portions of the surficial aquifer (i.e., screen midpoints set at more than 20 feet bgs). The differences in hydraulic conductivity observed in shallow and deeper wells suggests the presence of at least two zones of slight lithologic variations so as to create differences in apparent hydraulic conductivity in the surficial aquifer. No distinct confining unit is present, but the changes in lithology with depth apparently have effected a measurable change in hydraulic characteristics with depth at the site. The aquifer test results are presented in Appendix C.

Assuming an estimated effective porosity of 30 percent for the clayey sand unit, and based on the hydraulic gradient of 0.0014 ft/ft (see Figure 3.5) and the range of calculated hydraulic conductivities from the most recent slug tests, the range of calculated groundwater flow velocities for the upper lithologic zone is 0.245 to 40.8 ft/yr. The groundwater flow velocities in the deeper, lithologic unit of the surficial aquifer would be similar to the low-end range velocities estimated for the upper flow zone (i.e., 0.245 ft/yr).

3.5 CLIMATOLOGICAL CHARACTERISTICS

The climate at Charleston AFB is generally subtropical with warm summers and mild winters. In the winter, the average daily temperature is 55 degrees Fahrenheit (°F). The average daily temperature in the summer is 75°F. The total annual precipitation is 51.4 inches. The highest monthly precipitation typically occurs in July (7.6 inches) and August (6.7 inches), and the lowest monthly precipitation occurs from October through February (about 14.5 inches over 5 months) [based on record data from September 1949 through August 1979 (Detachment 3, 15th Weather Squadron, 1993)]. The estimated evapotranspiration (ET) rate for Charleston AFB is between 36 and 39 inches per year (HNUS, 1993). The calculated net precipitation, which can be used to estimate the potential for leachate generation, has been calculated to be between



NOTES:

1. WATER TABLE ELEVATIONS WERE DERIVED USING DATA FROM WELLS WITH SCREENED INTERVALS THAT EITHER CROSS, OR ARE PLACED NEAR, THE WATER TABLE SURFACE. THE REPRESENTATIVE WATER TABLE POTENTIOMETRIC SURFACE MAY BE AFFECTED FOR THOSE WELLS WITH SCREENS EXTENDING INTO DEEPER PORTIONS OF THE AQUIFER.
2. GENERALIZED GROUNDWATER FLOW LINES ARE BASED ON THE ASSUMPTION THAT THE SURFICIAL AQUIFER IS RELATIVELY ISOTROPIC AND HETEROGENOUS ON A LOCAL SCALE. ACTUAL FLOW LINES MAY INTERSECT EQUIPOTENTIAL LINES AT OTHER THAN RIGHT ANGLES DEPENDING ON THE DEGREE OF AQUIFER ANISOTROPY.
3. WELLS MW20-8, MW20-18D, AND ASW-1 WERE NOT USED IN THIS MAP CONSTRUCTION BECAUSE THEY ARE SCREENED IN THE LOWER PORTIONS OF THE SURFICIAL AQUIFER.
4. FOR WELLS CONTAINING LIGHT NONAQUEOUS-PHASE LIQUID, (LNAPL) FUEL, WATER LEVEL ELEVATIONS WERE DENSITY CORRECTED USING AN AVERAGE FULL-DENSITY FACTOR OF 0.75.

LEGEND

MW20-1	GROUNDWATER MONITORING WELL (INSTALLED 1988, 1990, OR 1993)
MW20-17	GROUNDWATER MONITORING WELL (INSTALLED 1995)
ASW-1 △	AIR SPARGING TEST WELL
	UNDERGROUND STORAGE TANK
	BUILDING
	FUEL DISPENSER ISLAND
145	SWMU 145: FORMER LOCATION OF LEAKING JP-4 UST
34.92	WATER TABLE ELEVATION, FEET ABOVE MEAN SEA LEVEL (MSL).
—34.50—	EQUIPOTENTIAL CONTOUR (FEET MSL); CONTOUR INTERVAL IS 0.1 FOOT.
	GENERALIZED GROUNDWATER FLOW DIRECTION

FIGURE 3.5

WATER TABLE POTENTIOMETRIC MAP (AUGUST 23, 1995)

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Risk-Based Approach To Remediation
Charleston AFB, South Carolina

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12.4 and 15.4 inches per year. Excessive surface runoff may also occur as a result of storm events in the area. The maximum 1-year, 24-hour rainfall event for Charleston AFB has been estimated to be about 4 inches [National Oceanic and Atmospheric Administration (NOAA), 1963].

3.6 LAND USE

3.6.1 Site Access

Site ST-27 is located in the north-central portion of the Base adjacent to Building 575. The entire extent of Site ST-27 and the adjacent SWMUs is within the boundaries of the Base (Figure 1.2), which is surrounded by a chainlink fence. The Base is under manned guard 24 hours per day, 7 days per week. The site is located within a designated aircraft maintenance area located west of the major taxiways for primary Runway 15/33. Access to these areas is restricted. Additionally, the site is capped by 8 to 14 inches of concrete, which precludes direct exposure of onsite receptors (e.g., Base personnel) to potentially impacted soils and groundwater.

3.6.2 Current Land Use

Site ST-27 has been maintained as an active fuel storage and aircraft maintenance area for flight operations at Charleston AFB since 1958. Currently, two 4,000-gallon USTs and one 10,000-gallon UST, all of which are enclosed in some form of secondary containment (i.e., an impermeable membrane or a concrete vault), are located at Site ST-27. These tanks are part of the operational Building 575 UST system. The adjacent SWMUs included a former washrack facility used to clean aircraft and power equipment and to collect and treat the wastewater generated by the cleaning operations. Integrity inspections and separate environmental characterization efforts have been conducted at these SWMUs in accordance with the Base-wide RCRA permit (HNUS, 1993 and 1995). Other on-Base facilities consist of industrial flight operations support and administration facilities; single-family, duplex, and unaccompanied housing units in the on-Base housing area; medical facilities; a variety of outdoor recreational areas such as a golf course, a skeet and trap range, soccer fields, and picnic grounds; a fitness center; and other open space areas.

Most of the area surrounding Site ST-27 and adjacent SWMUs comprises the Base industrial aircraft operations and maintenance facilities. This industrial land use supports aircraft maintenance hangars, component repair shops, squadron operations buildings, Base operations, a passenger terminal, an air freight terminal, and the Combat Control Squadron building. The city of North Charleston surrounds Charleston AFB on all sides (Figure 1.1). The predominant land uses in the city are residential and commercial, with apartment complexes located near Charleston AFB. Commercial developments line the major roadways. Industrial parks also are scattered throughout the city, including a large industrial area is located just south of Charleston AFB along the Ashley River. The City of Hanahan, which is located east of North Charleston and Charleston AFB, is primarily residential.

3.6.3 Proposed Land Use

The Base is active and is not on any known US Department of Defense closure lists. Future land use changes for some portions of the Base are being considered; however, according to the Base master plan, the area of Site ST-27 and adjacent SWMUs remain designated as part of the aircraft maintenance and operation facilities. After UST system decommissioning in 1997, it is expected that the land use at and immediately surrounding Site ST-27 will remain industrial. No redevelopment plans currently exist for the site. Therefore, the reasonably expected future land use at and near the site will remain industrial.

3.6.4 Water Resources

Most drinking water for the Charleston area is not obtained from groundwater sources, because the public water supply system (which utilizes surface water resources) is sufficient to meet current demands. The public water supply system, provided to the Base by the Charleston Commission of Public Works, consists of three intakes that are located on the Edisto River (about 25 miles northwest of the Base), Goose Creek Reservoir (about 2 miles northeast of the Base), and Foster Creek (about 8 miles north of the Base). The Base provides no treatment of the water, but does maintain and operate the distribution system under a drinking water supply permit.

However, groundwater within the vicinity of Charleston AFB is used for both industrial and domestic supply purposes. These groundwater wells, which vary in depth from 300 to 500 feet bgs, draw from aquifers below the confining Cooper Formation. The closest known domestic well is located approximately 2.2 miles downgradient (southwest) of Site ST-27, approximately 1.2 miles downgradient from the southwestern boundary of Charleston AFB. Domestic uses of local deep groundwater resources include home heat pump systems and lawn and garden irrigation.

3.7 POPULATION DEMOGRAPHICS

As described in Section 1.3, approximately 4,500 active duty military personnel and 3,600 Air Force reservists serve at Charleston AFB. Nearly 1,900 of the active military personnel reside on-Base. The Base also employs 1,800 civilian workers.

3.8 ECOLOGICAL RESOURCES

Six major ecological communities have been identified at Charleston AFB (ES, 1983): open water, freshwater marsh, swamp forest, oak and pine forest, human-influenced areas, and human-dominated areas. The two ecological communities that can be found adjacent to Site ST-27 include human-influenced and human-dominated. The human-influenced areas consist of powerline and railroad right-of-ways where vegetation is mowed only when it becomes overgrown and unsightly. The human-dominated areas include regularly maintained grass alongside roads, taxiways, dwellings, and shops. Common grasses usually found in these areas include Bermuda, centipede, rye, and St. Augustine. Animal life such as the eastern mole, opossum,

rats, mice, and several hardy bird species can be occasionally found in these areas (ES, 1983).

At Site ST-27, the concrete cover and activity level associated with aircraft maintenance in this generally heavily developed area effectively limit the presence of wildlife populations to the occasional song bird. The only vegetated areas present are two grassy areas (Figure 3.5) covered with maintained grass and forb communities. These areas do not support trees, and the root zone likely does not extend to the water table. The low structural diversity, the surrounding industrial development, and the managed character of these vegetated area likely limit their attractiveness to wildlife and they are not considered suitable habitat for most species.

SECTION 4

TIER 1 ANALYSIS AND IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

This section provides an overview of the regulatory requirements for a risk-based, tiered approach to identification of COPCs, and reviews the preliminary conceptual site model (CSM) developed for Site ST-27 in the CAP work plan (Parsons ES, 1994) as a means of selecting appropriate regulatory screening criteria to identify COPCs in affected site media (i.e., chemicals present at concentrations that could pose a risk to human and/or ecological receptors exposed to the affected media). This section then presents a screening-level Tier 1 analysis in accordance with SCDHEC (1995) guidance to select the COPCs that will be the focus of this CAP. The COPCs for Site ST-27 are identified in the Tier 1 analysis based on estimated risks to human health and the environment posed by maximum detected contaminant concentrations. Conservative land use and exposure assumptions are used in the Tier 1 screening analysis to ensure that the nature and extent of any COPCs that could pose a risk to human or ecological receptors at or near the site are fully described (Section 5), and that these chemicals are fully evaluated in subsequent tier analysis through quantitative fate and transport and receptor exposure evaluations (Sections 6 and 7).

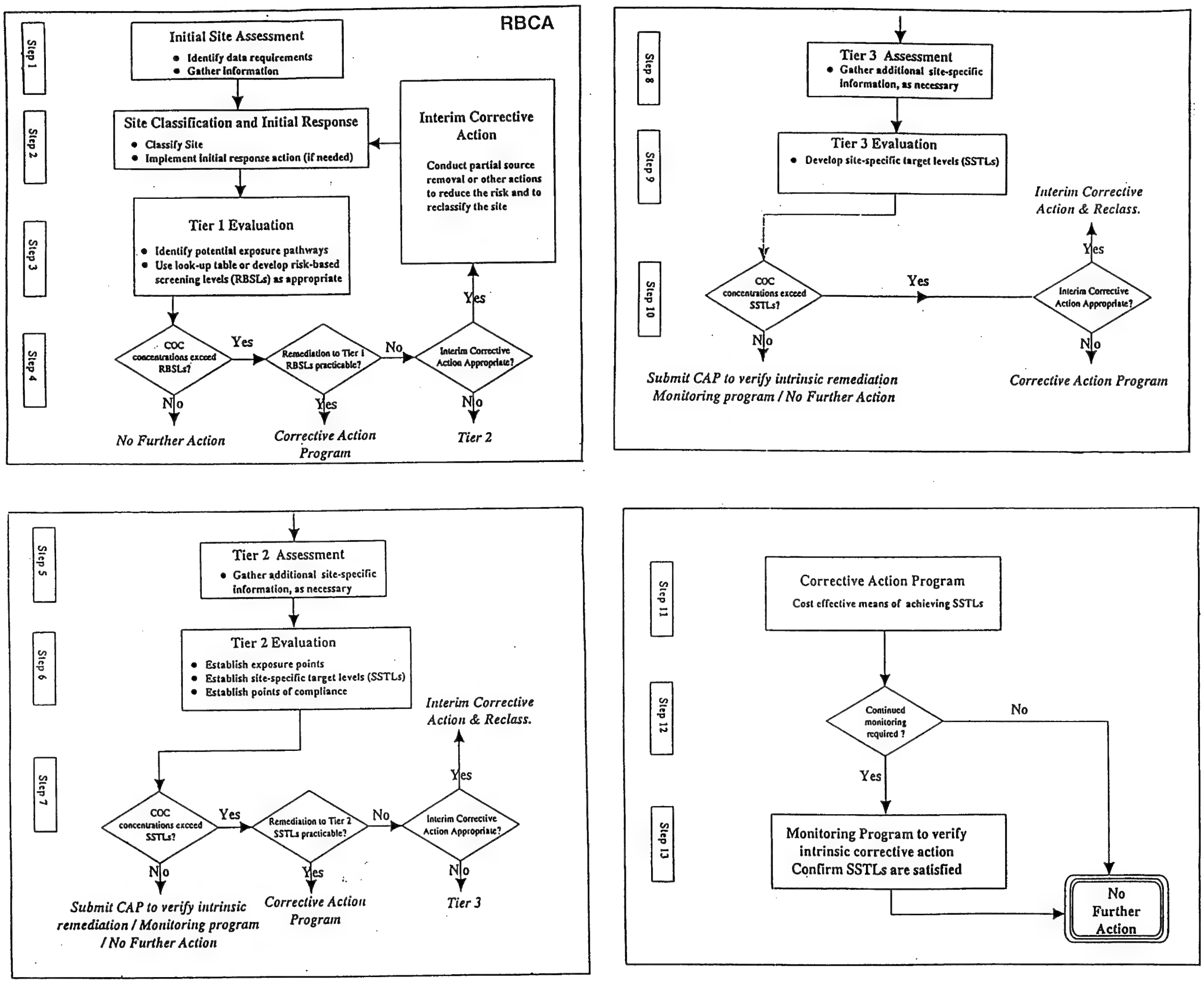
4.1 REGULATORY OVERVIEW OF THE TIERED APPROACH

This section describes South Carolina's tiered approach for risk-based corrective action at petroleum release sites. Figure 4.1 illustrates the state's three-tiered approach for evaluation of petroleum releases. The approach integrates site assessment, risk assessment, risk management, monitoring, and corrective action (SCDHEC, 1995). Specifically, the remainder of Section 4 discusses the steps taken during the Tier 1 analysis. Sections 5, 6, and 7 describe subsequent tier analyses, as appropriate. In general, the tiered approach emphasizes iterative steps of site assessment, risk evaluation, and associated action decisions.

4.1.1 Site Prioritization

Based on initial release information, and subsequently upon completion of each tier evaluation, the site at which a release has occurred must be classified based on the current and projected degree of hazard to human health and the environment. A site can be classified into one of five categories. The categories, as defined in the guidance (SCDHEC, 1995), are described below:

- Category 1 (highest priority classification)--Defined as a site where the release poses an emergency (immediate health or environmental threat);



Source: SCDHEC, 1995.

FIGURE 4.1

OVERVIEW OF SCDHEC THREE-TIERED APPROACH FOR RBCA FOR PETROLEUM RELEASES

Site ST-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

- Category 2 (second priority classification)--Defined as a site where the release poses a significant near-term (0- to 1-year) threat to human health or the environment;

- Category 3 (third priority classification)--Defined as a site where the release poses a short-term (1- to 2-year) threat to human health and the environment;

- Category 4 (fourth priority classification)--Defined as a site where the release poses a long-term (> 2-year) threat to human health and the environment; and

- Category 5 (lowest priority classification)--Defined as a site with a release that: 1) does not meet any of the characteristics of the other four categories, or 2) where there is no demonstrable threat to human health or the environment, but where data indicate that COPCs are above the Tier 1 RBSLs, and further assessment is needed.

The guidance states that prioritization is an on-going process and is based on available information. Releases may be reclassified subsequent to interim remedial actions, further assessment information, and corrective actions (SCDHEC, 1995) (see Section 4.5 for Site ST-27 classification following the Tier 1 analysis).

4.1.2 Description of the Tier 1 Process

In its guidance document titled *Risk-Based Corrective Action for Petroleum Releases* (SCDHEC, 1995), the State of South Carolina has issued screening-level target concentrations (also referred to as Tier 1 target levels or nonsite-specific RBSLs) for petroleum analytes in various media. This guidance provides a protocol for making risk-based decisions concerning corrective actions for releases of petroleum and petroleum-based products (SCDHEC, 1995). The guidance document is based on the ASTM (1994) *Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites,* and is in conformance with the South Carolina UST Control Regulations, R.61-92, Section 280.

The State of South Carolina considers the Tier 1 RBSLs to be protective of human health because the values are based on conservative or maximum exposure assumptions (i.e., site chemical concentrations at or below the target levels are not expected to cause adverse health effects in human receptors). The Tier 1 RBSLs are provided for various land use scenarios and assumptions to assist in determining site COPCs. Tier 1 soil RBSLs are presented in a "look-up" table for both residential and commercial land use scenarios. Tier 1 groundwater RBSLs also are presented in the guidance "look-up" tables and are based on unrestricted groundwater use assumptions (e.g., current or future use of the shallow aquifer as a source of drinking water).

Although not specifically tabulated in the SCDHEC guidance, soil RBSLs (for the ingestion or dermal exposure route) based on an industrial land use scenario are available. South Carolina is regulated under EPA Region IV, but Region IV and all other EPA regional offices adopt the EPA Region III soil contaminant RBSLs. Industrial-based RBSLs for many common environmental contaminants may be

obtained from USEPA Region III (1996), national or regional soil screening guidance (which is consistent with SCDHEC methodology), or can be calculated using simple risk assessment algorithms. The industrial land use scenario is appropriate when 1) land uses at the site and surrounding area are currently identified as industrial; 2) residential land use currently does not occur at or near the site; 3) a future residential land use scenario is unrealistic; and 4) it can be reasonably anticipated that the future use of the site will be restricted to industrial or commercial activities. The applicability of the industrial land use scenario for Site ST-27 is explained in Section 4.2.

The state has promulgated surface water standards for the protection of aquatic organisms, and these standards are considered to be appropriate for use as RBSLs for aquatic receptors in surface waters affected by site contaminants (SCDHEC, 1993). However, SCDHEC (1995) guidance does not specify soil or groundwater RBSLs for ecological receptors. In lieu of RBSLs specifically developed to be protective of plants or terrestrial wildlife, Tier 1 screening of soil and groundwater chemicals is conducted using only the conservative, human health-protective RBSLs.

In summary, the purpose of using SCDHEC (1995) and USEPA Region III (1996) RBSLs as a screening tool is to focus corrective action evaluation on only those compounds and environmental media that potentially pose a threat to human health or the environment. The preliminary CSM for Site ST-27 is used to help identify the appropriate RBSLs for exposure scenarios at this site in Section 4.2. Section 4.3 presents the methodology used to select appropriate RBSLs for Site ST-27, and Section 4.4 summarizes the analytes with site concentrations that exceed the selected RBSLs (i.e., the site COPCs). Subsequent contaminant nature and extent analysis (Section 5) is limited to those analytes that exceed the conservative, matrix-specific Tier 1 screening RBSLs. Analytes with site concentrations below the health-protective screening levels are not considered to be a threat to human health or the environment (i.e., are no longer considered COPCs), and therefore are not retained for further risk/remedial analysis.

4.2 PRELIMINARY CONCEPTUAL SITE MODEL REVIEW

Figure 4.2 presents a CSM based on the preliminary CSM developed for Site ST-27 in the CAP work plan (Parsons ES, 1994). The model presented in Figure 4.2 was developed using data collected during the previous site investigations and based on a review of potential receptors and feasible exposure scenarios. The purpose of developing a CSM is to evaluate available information on site characteristics, including:

- Potential contaminant sources;
- Media affected by contaminant releases;
- Mechanisms of contaminant release (e.g., leaching and volatilization);
- Potential human and ecological receptors;
- Potential receptor exposure points based on conservative, reasonable land use assumptions; and

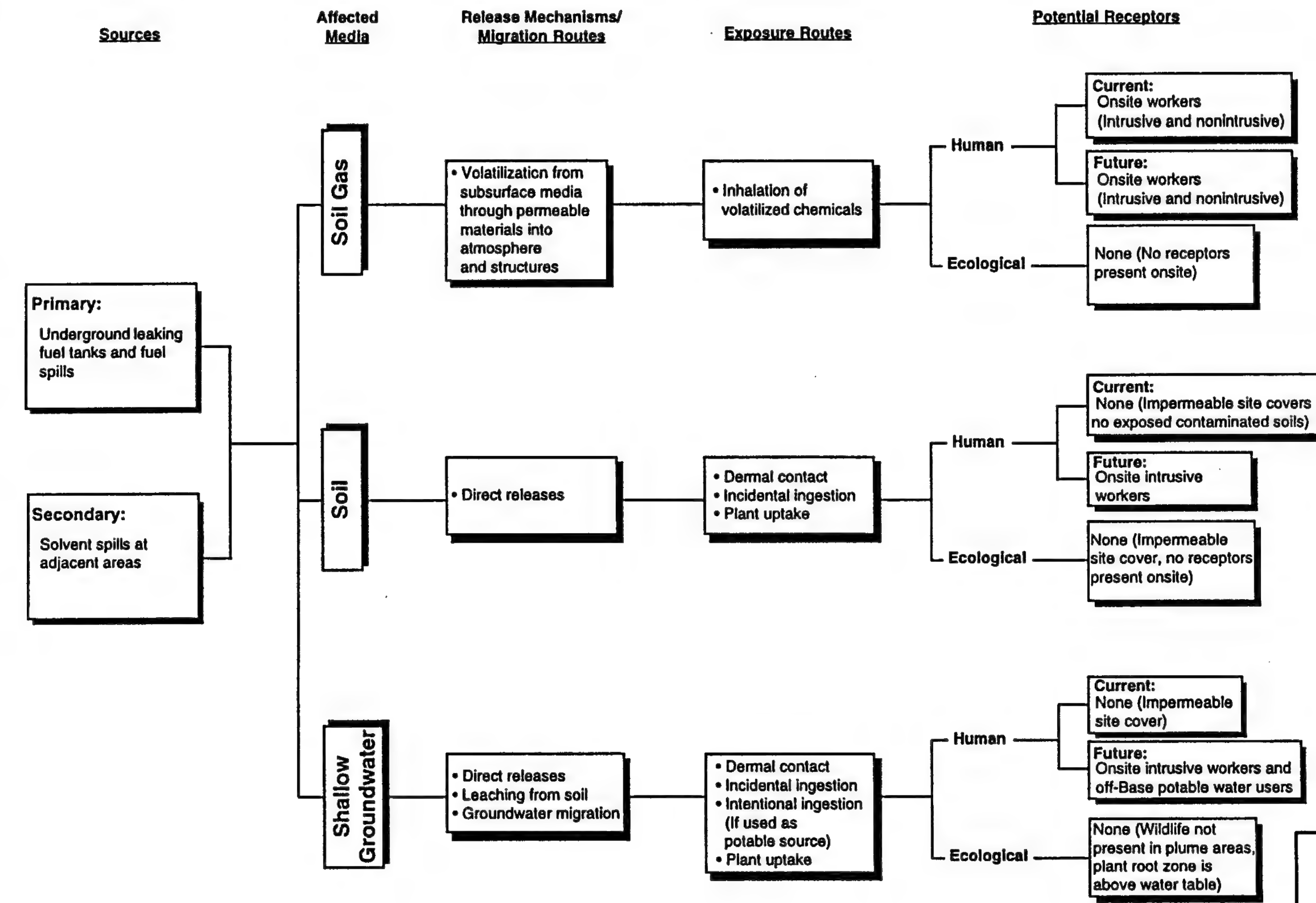


FIGURE 4.2

PRELIMINARY CONCEPTUAL SITE MODEL

Site ST-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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- Routes of possible receptor exposure (e.g., inhalation, ingestion, or dermal contact).

The preliminary CSM presented in the work plan for this CAP was used to identify data gaps in site information needed to quantify exposure of receptors to site contaminants, and to guide the field activities conducted during the risk-based investigation at the site. The components of the preliminary CSM are described in the work plan (Parsons ES, 1994). For the purposes of the Tier 1 analysis of chemicals detected at the site, the work plan model was slightly revised (Figure 4.2) and was used to identify potentially completed receptor exposure pathways. For an exposure pathway to be completed, there must be a contaminant source, a release mechanism and a contaminant migration pathway, an exposure point, a receptor, and an exposure route. If any of these components is missing, the pathway is incomplete, and receptors are not at risk from exposure to site contaminants.

Based on the preliminary CSM, soil gas, soil, and shallow groundwater represent the affected physical media at Site ST-27. No surface water is present within approximately 750 feet of the site, and available data indicate that no contaminant migration pathway from the site to surface water, either through overland runoff or groundwater discharge, is completed. Therefore, surface water is not considered to be an affected medium.

As discussed in Section 1.3, Charleston AFB is an active military installation, and home to the 437th AW. The AW's primary mission is to provide military airlift services worldwide. Charleston International Airport shares runways and industrial airpark space with the Base under a joint-use agreement. In summary, surrounding land use is primarily light industrial and commercial, although some private residences are located within a few thousand feet of the Base.

Considering the most recent land use plans for Site ST-27 and the current activities taking place in the area, it is highly likely the site (which is located in the north-central portion of Charleston AFB) will continue to be maintained as an industrial area with limited access. As discussed earlier, the site is currently an active maintenance facility on the aircraft apron. Although the maintenance hangar (Building 575) and USTs at Site ST-27 are scheduled for removal in 1988, Site ST-27 and the surrounding area will remain as a parking apron for C-17 aircraft. Should portions of Charleston AFB become available for transfer to civilian authorities in the future, it is highly improbable that residential development would occur at Site ST-27 or within areas adjacent to and downgradient from the site. Current land use trends around the Base and Charleston International Airport indicate that the areas likely to be affected by site-related contamination will not be available or desirable for non-military residential development. Land uses in the entire area will most likely remain commercial and industrial. There are no residential developments within 2,000 feet crossgradient from and 4,000 feet generally downgradient from Site ST-27. Therefore, future residential development for the site is not a reasonable assumption.

Based on these land use assumptions, onsite worker populations are the only current or likely future onsite human receptors. As there is no on-Base beneficial use of

groundwater from the affected shallow aquifer, and as Site ST-27 is covered with concrete pavement and buildings, current onsite workers could reasonably be exposed to air potentially affected by chemicals volatilizing from subsurface media and seeping into buildings through foundation cracks or utilities. Future workers also could include those involved in construction (e.g., during the scheduled demolition of Building 575) or other intrusive maintenance activities. Therefore, future onsite workers could be exposed to contaminants in subsurface soils and shallow groundwater, as well as air. No exposure pathways to current off-site receptors are thought to be completed. In light of the existence of downgradient, off-Base potable water wells completed in the affected shallow aquifer, future off-site human receptors could potentially be exposed to site contaminants through ingestion of, inhalation of, or dermal contact with contaminants in groundwater extracted for potable use (Figure 4.2). However, completion of this exposure pathway is considered unlikely given the distance to the closest potable water well (i.e., more than 11,600 feet downgradient from Site ST-27).

Although numerous plant and wildlife species are known to occur on and near Charleston AFB (see Section 3.9), Site ST-27 is in a heavily developed, active industrial portion of the Base that is extensively covered with artificial impermeable structures (e.g., buildings and pavement). The industrial setting and operational activity levels in the immediate site vicinity, coupled with the lack of suitable wildlife habitat, essentially preclude the presence of wildlife populations at the site. No significant plant communities are present, and the lack of surface water bodies in the site area eliminates the possibility of aquatic receptors. The only vegetation at the site consists of two islands of landscaped grasses west of Building 575 (Figure 1.4). For risk assessment purposes, domesticated species such as landscape plantings are not evaluated as ecological receptors (USEPA, 1994a). Moreover, these small vegetated areas do not support diverse plant species and do not provide adequate cover, foraging, or breeding/nesting habitat to attract or sustain wildlife populations. Wildlife at the site is probably limited to opportunistic feeders such as transient songbirds that may pass through the area. Based on the lack of vegetation and suitable wildlife habitat, and on the absence of contaminant migration pathways in media to which wildlife could readily be exposed (e.g., surface water), no ecological receptors are likely to be exposed to contaminants in site media under current or anticipated future land uses.

The media affected by fuel- and nonfuel-related organic contaminants at Site ST-27, and the contaminant migration pathways and receptors discussed above were identified based on the preliminary CSM (Figure 4.2). Following the Tier 1 analysis (Section 4.3) and the quantitative fate and transport analysis presented in Section 6, a revised CSM for the site is presented in Section 7.

4.3 TIER 1 SCREENING ANALYSIS

It is the intention of the Air Force to obtain approval for a corrective action for Site ST-27 that will protect receptors from unacceptable exposures to site-related chemicals. To accomplish this objective, the COPCs that drive potential risks and impact the final remedial requirements at this site must be identified. Previous IRP site investigations (GLS, 1988; Versar, Inc., 1992; EA, 1993), the AFCEE-sponsored bioventing pilot test (ES, 1993), and the risk-based work plan (Parsons ES, 1994) identified the fuel-

related hydrocarbons, such as the BTEX compounds, chlorobenzene, and PAH compounds, as site-related contaminants in soil and groundwater at Site ST-27. Several nonfuel chlorinated organic compounds (detected at low concentrations in a few wells at the site) also were reported. The sources of these nonfuel organic compounds are suspected to be the adjacent SWMUs associated with the aircraft washrack oil/water separation system. Although these SWMUs are not considered to be part of Site ST-27, the nonfuel-related organic compounds were retained for the Tier 1 analysis because they are present within the media affected by Site ST-27 and are commingled with site chemicals. These chemical constituents were initially identified as contaminants based on existing site characterization data, the chemical nature of the suspected sources (i.e., JP-4 jet fuel and MOGAS for Site ST-27 and possibly nonfuel/solvent compounds migrating from SWMUs adjacent to Site ST-27), and the analytical requirements specified by the SCDHEC (1995) for petroleum-contaminated soils and groundwater.

4.3.1 Selection of Appropriate Tier 1 Soil, Groundwater, and Air RBSLs

South Carolina (SCDHEC, 1995) and USEPA Region III (1996) RBSLs are based on 1) analyte-specific toxicity data; 2) an exposure-pathway-specific cancer target risk limit of 10^{-6} (i.e., there is an added lifetime cancer risk for people near the site of 1 additional cancer above the normal background level in 1 million people, expressed as 10^{-6} or 1 in 1 million) and a noncancer hazard quotient of less than or equal to 1; and 3) appropriate receptor scenario assumptions. Regarding the second criterion, note that USEPA (1994b) states that cancer occurs randomly within any population in the United States at a rate of about one in three persons (30-35 percent), and this is defined as "normal background level." Regarding the third criterion, appropriate receptor scenarios assumptions must be based on current and reasonably anticipated future land use considerations for the site, as discussed in Section 4.2.

Based on the land use assumptions and potential receptors reviewed in Section 4.2, commercial and industrial RBSLs were selected as the Tier 1 soil screening values for Site ST-27 for purposes of evaluating risk from exposure to soils [the lesser of the SCDHEC (1995) and USEPA Region III (1996) was used as the comparative value]. These land use scenarios typically use less conservative exposure assumptions in calculating RBSLs compared to those used under a residential scenario. Furthermore, industrial exposure factors tend to be less conservative than those incorporated into commercial scenarios. For example, it may be assumed that there are fewer receptor visits (i.e., lower exposure frequency) to an industrial site than to a commercial site. As discussed throughout Section 4.3, commercial and industrial RBSLs were selected and compared to maximum analyte concentrations in soil. SCDHEC (1995) guidance suggests that exposure factors used in the soil RBSL calculations (for the ingestion and dermal exposure pathways) be based on a residential scenario. Therefore, the results of a residential-based comparison are qualitatively presented in Section 4.3.2.

Regarding groundwater, Charleston AFB currently receives its domestic water supply from municipal sources (Section 3). In addition, the previous RI/FS risk assessment did not identify any users of on-Base groundwater (Versar, Inc., 1992). However, groundwater is occasionally used as a source of potable water for off-Base

residences, with the closest downgradient well being more than 11,600 feet (2.2 miles) from Site ST-27. Therefore, the CAP risk analysis and conclusions conservatively consider and address the possibility of future unrestricted use of groundwater resources potentially impacted by Site ST-27 (i.e., unrestricted groundwater use will be assumed for the surrounding off-Base and downgradient areas). To facilitate these considerations, Tier 1 groundwater RBSLs used in this CAP are based on an assumption of unrestricted future use of groundwater. These Tier 1 RBSLs assume possible receptor exposure to site-contaminated groundwater through potable use.

Regarding air, SCDHEC (1995) guidance provides RBSLs for the BTEX compounds, but not for PAHs, stating that RBSLs for these compounds are not of concern because of their associated low volatilities. Therefore, only BTEX RBSLs for ambient air were evaluated in the Tier 1 analysis [i.e., in addition to the SCDHEC RBSLs, only BTEX values for ambient air were selected from USEPA Region III (1996) RBSL tables].

4.3.1.1 RBSLs for Soil

The industrial- and commercial-scenario RBSLs (for ingestion and dermal exposure to soils) are presented in Table 4.1 for fuel and nonfuel chemicals detected at Site ST-27. The SCDHEC (1995) guidance provides commercial-scenario RBSLs for ingestion of, and dermal contact with, common petroleum constituents in soil. However, industrial-scenario RBSLs are not presented in the SCDHEC guidance, nor are RBSLs for nonfuel-related organic chemicals such as methylene chloride. Therefore, generic industrial-scenario RBSLs were developed using USEPA Region III's (1996) risk-based concentration table and supplemental guidance document. USEPA Region III's target soil concentrations for an industrial scenario are based on adult occupational exposure (e.g., occupational exposure frequency and duration), including an assumption that 50 percent of total incidental soil ingestion is work-related. The algorithms and assumptions used to calculate these RBSLs (with the exception of those provided in SCDHEC's look-up tables for sandy soils) are presented in Appendix D.

Soil RBSLs that are protective of groundwater quality (i.e., that ensure groundwater will remain suitable for potable use) also have been developed by SCDHEC and USEPA Region III (Table 4.2). These soil RBSLs are "back calculated" using groundwater RBSLs (Section 4.3.1.2) to determine the allowable contaminant leachate concentrations that can be released from soils into underlying groundwater without causing exceedances of applicable groundwater RBSLs. Information regarding the Tier 1 soil RBSLs protective of groundwater (from SCDHEC and USEPA Region III sources) is presented in Appendix D.

4.3.1.2 RBSLs for Groundwater

RBSLs for groundwater, which are used to derive the above-mentioned target soil concentrations, are presented in Table 4.3. With the exception of the BTEX compounds, the majority of unrestricted-use groundwater RBSLs were obtained from USEPA Region III (1996) screening guidance, as the SCDHEC (1995) list is limited to target concentrations for fuel compounds. Information regarding the Tier 1 RBSLs for

TABLE 4.1
TIER 1 SOIL CONTAMINANT SCREENING CRITERIA
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	SCDHEC Commercial RBSL[a/]	USEPA Industrial RBSL	Units
Benzene[b/]	99	200	mg/kg
Toluene[b/]	200000	410000	mg/kg
Ethylbenzene[b/]	100000	200000	mg/kg
Xylenes (Total)[b/]	1000000	1000000	mg/kg
Naphthalene[b/]	41000	82000	mg/kg
Benzo(a)anthracene[b/]	3.9	7.8	mg/kg
Benzo(b)fluoranthene[b/]	3.9	7.8	mg/kg
Benzo(k)fluoranthene[b/]	39	78	mg/kg
Chrysene[b/]	390	780	mg/kg
Acenaphthene	-[c/]	120000	mg/kg
Anthracene	-	610000	mg/kg
Benzo(a)pyrene	-	0.78	mg/kg
bis(2-Ethylhexyl)phthalate	-	410	mg/kg
Chlorobenzene	-	41000	mg/kg
Fluoranthene	-	82000	mg/kg
Fluorene	-	82000	mg/kg
Pyrene	-	61000	mg/kg
1,2,4-Trimethylbenzene	-	100000	mg/kg
1,3,5-Trimethylbenzene	-	100000	mg/kg
2-Methylnaphthalene	-	-	-
Phenanthrene	-	-	-
1,2,3,4-Tetramethylbenzene	-	-	-
1,2,3-Trimethylbenzene	-	-	-

Sources: SCDHEC, 1995; USEPA Region III, 1995.
[a/]RBSL = risk-based screening level.
[b/]The lesser of the SCDHEC and USEPA values is used in comparisons with site concentrations.
[c/]"-" = value not available.

TABLE 4.2
TIER 1 SOIL LEACHABILITY SCREENING CRITERIA
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	SCDHEC Leachability RBSL[a/]	USEPA Leachability RBSL	Units
Benzene[b/]	0.007	0.016	mg/kg
Toluene[b/]	1.7	4	mg/kg
Ethylbenzene[b/]	1.5	4	mg/kg
Xylenes (Total)[b/]	44	59.2	mg/kg
Naphthalene[b/]	0.2	24	mg/kg
Benzo(a)anthracene[b/]	0.7	0.56	mg/kg
Benzo(b)fluoranthene[b/]	0.66	3.2	mg/kg
Benzo(k)fluoranthene[b/]	4.6	3.2	mg/kg
Chrysene[b/]	0.66	0.8	mg/kg
Acenaphthene	-[c/]	160	mg/kg
Anthracene	-	3440	mg/kg
Benzo(a)pyrene	-	3.2	mg/kg
bis(2-Ethylhexyl)phthalate	-	8.8	mg/kg
Chlorobenzene	-	0.48	mg/kg
Fluoranthene	-	784	mg/kg
Fluorene	-	128	mg/kg
Pyrene	-	1120	mg/kg
1,3,5-Trimethylbenzene	-	0.208	mg/kg
2-Methylnaphthalene	-	-	-
Phenanthrene	-	-	-
1,2,3,4-Tetramethylbenzene	-	-	-
1,2,3-Trimethylbenzene	-	-	-
1,2,4-Trimethylbenzene	-	-	-

Sources: SCDHEC, 1995; USEPA Region III, 1995.

[a/]RBSL = risk-based screening level for sandy soils.

[b/]The lesser of the SCDHEC and USEPA values is used in comparisons with site concentrations.

[c/]"-" = value not available.

TABLE 4.3
TIER 1 GROUNDWATER CONTAMINANT SCREENING CRITERIA
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	SCDHEC RBSL[a/]	USEPA RBSL	Units
Benzene[b/]	5	0.36	µg/L
Toluene[b/]	1000	750	µg/L
Ethylbenzene[b/]	700	1300	µg/L
Xylenes (Total)[b/]	10000	12000	µg/L
Naphthalene[b/]	25	1500	µg/L
Acenaphthene	-[c/]	2200	µg/L
Acetone	-	3700	µg/L
Chlorobenzene	-	39	µg/L
1,1-Dichloroethane	-	810	µg/L
cis-1,2-Dichloroethene	-	61	µg/L
Diethylphthalate	-	29000	µg/L
2,4-Dimethylphenol	-	730	µg/L
Di-n-butylphthalate	-	3700	µg/L
Methylene Chloride	-	4.1	µg/L
2-Methylphenol(o-Cresol)	-	1800	µg/L
4-Methylphenol(p-Cresol)	-	180	µg/L
Phenol	-	22000	µg/L
Trichloroethene	-	1.6	µg/L
1,1,1-Trichloroethane	-	1300	µg/L
1,2,4-Trimethylbenzene	-	300	µg/L
1,3,5-Trimethylbenzene	-	300	µg/L
2-Methylnaphthalene	-	-	-
Phenanthrene	-	-	-
1,2,3,4-Tetramethylbenzene	-	-	-
1,2,3-Trimethylbenzene	-	-	-

Sources: SCDHEC, 1995; USEPA Region III, 1995.

[a/]RBSL = risk-based screening level.

[b/]The lesser of the SCDHEC and USEPA values is used in comparisons with site concentrations.

[c/]"-" = value not available.

groundwater (from SCDHEC and USEPA Region III sources) is presented in Appendix D.

4.3.1.3 RBSLs for Air

RBSLs for air are presented in Table 4.4. As discussed earlier, the RBSL table is limited to values for BTEX compounds only. Information regarding the Tier 1 RBSLs for air (from SCDHEC and USEPA Region III sources) is presented in Appendix D.

4.3.2 Screening to Identify COPCs in Soils, Groundwater, and Air

The COPCs to be evaluated in detail in this CAP are based on a comparison of measured site concentrations to SCDHEC- and/or USEPA-approved RBSLs for soil and groundwater. As discussed above, commercial and industrial soil RBSLs and unrestricted groundwater RBSLs were selected as the appropriate set of Tier 1 screening values. Tables 4.5 through 4.8 compare the appropriate site concentrations for each compound measured in soil, groundwater, and soil gas at Site ST-27 during the 1993 bioventing pilot test and the 1995/1996 risk-based sampling event to the appropriate matrix- and/or receptor-specific RBSLs. Maximum detected values are used for comparison to dermal contact/ingestion soil and groundwater RBSLs; average site concentrations are used for comparison to soil leachability RBSLs. Maximum detected soil gas concentrations are used for comparison to RBSLs for inhalation of vapors present in ambient air. The comparison between measured soil gas concentrations to ambient air vapor RBSLs may be overly conservative. It is important to note that soil flux data were not collected at the site, nor were data available for evaluation of indoor or outdoor VOCs. Intuitively, however, soil gas measurements (measurements taken beneath the concrete apron) are suspected to potentially overestimate actual and potential indoor and outdoor ambient air concentrations. This approach was used as part of the Tier 1 analysis; however, chemical fate model results will be presented in Section 6 to determine whether any exposure pathway involving soil gas/air could be complete at the site.

If the site comparison concentration does not exceed the most stringent respective RBSL, the compound is not identified as a COPC, and it is not retained for further Tier 2 evaluation. No additional remediation would be warranted for such compounds in order to protect human health and the environment from exposures to these compounds, given the current and foreseeable uses of the site. If the site comparison concentration exceeds the appropriate RBSL, the compound is identified as a COPC and retained for further quantitative fate and transport and risk analyses. Tier 1 screening for soil, groundwater, and air COPCs is summarized in Tables 4.5 through 4.8.

4.4 SUMMARY OF SITE ST-27 COPCS

Table 4.9 summarizes the COPCs for soil, ambient and indoor air, and groundwater for Site ST-27. Based on comparisons of the maximum site chemical concentrations to the RBSLs for ingestion and dermal exposure to soil (Table 4.5) and the average site chemical concentrations to the RBSLs for potential leachability from soil to groundwater (Table 4.6), benzene, toluene, ethylbenzene, xylene, naphthalene,

TABLE 4.4
TIER 1 AIR
CONTAMINANT SCREENING CRITERIA
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	SCDHEC RBSL[a/]	USEPA RBSL	Units[b/]
Benzene	0.22	0.22	$\mu g/m^3$
Toluene	420	420	$\mu g/m^3$
Ethylbenzene	1000	1000	$\mu g/m^3$
Xylenes (Total)[c/]	730	7300	$\mu g/m^3$

Sources: SCDHEC, 1995; USEPA Region III, 1995.
[a/]RBSL = risk-based screening level.
[b/]$\mu g/m^3$ = microgram per cubic meter.
[c/]The lesser of the SCDHEC and USEPA values is used in comparisons with site concentrations.

TABLE 4.5
TIER 1 EVALUATION
COMPARISON OF SITE SOIL CONCENTRATIONS TO DIRECT-CONTACT RBSLs
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	Detected Site Maximum Concentration	SCDHEC Commercial RBSL[a/]	Max. Conc. Exceeds Commercial RBSL	USEPA Industrial RBSL	Max. Conc. Exceeds Industrial RBSL	Units
Benzene	34	99	No	200	No	mg/kg
Toluene	320	200000	No	410000	No	mg/kg
Ethylbenzene	150	100000	No	200000	No	mg/kg
Xylenes (Total)	620	1000000	No	1000000	No	mg/kg
Naphthalene	48	41000	No	82000	No	mg/kg
Benzo(a)anthracene	0.26	3.9	No	7.8	No	mg/kg
Benzo(b)fluoranthene	0.056	3.9	No	7.8	No	mg/kg
Benzo(k)fluoranthene	0.026	39	No	78	No	mg/kg
Chrysene	0.064	390	No	780	No	mg/kg
Acenaphthene	1.5	-[b/]	-	120000	No	mg/kg
Anthracene	0.38	-	-	610000	No	mg/kg
Benzo(a)pyrene	0.036	-	-	0.78	No	mg/kg
bis(2-Ethylhexyl)phthalate	26	-	-	410	No	mg/kg
Chlorobenzene	21	-	-	41000	No	mg/kg
Fluoranthene	0.65	-	-	82000	No	mg/kg
Fluorene	2.3	-	-	82000	No	mg/kg
Pyrene	0.67	-	-	61000	No	mg/kg
1,2,4-Trimethylbenzene	360	-	-	100000	No	mg/kg
1,3,5-Trimethylbenzene	162	-	-	100000	No	mg/kg
2-Methylnaphthalene	67	-	-	-	-	mg/kg
Phenanthrene	2	-	-	-	-	mg/kg
1,2,3,4-Tetramethylbenzene	160	-	-	-	-	mg/kg
1,2,3-Trimethylbenzene	185	-	-	-	-	mg/kg

Sources: SCDHEC, 1995; USEPA Region III, 1996.
[a/]RBSL = risk-based screening level.
USEPA Region III (1995) criterion.
[b/]"-" = value not available.

TABLE 4.6
TIER 1 EVALUATION
COMPARISON OF SITE SOIL CONCENTRATIONS TO SOIL LEACHABILITY RBSLs
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	Average Site Concentration	SCDHEC Leachability RBSL[a/]	Avg. Conc. Exceeds SCDHEC RBSL	USEPA Leachability RBSL	Avg. Conc. Exceeds USEPA RBSL	Units
Benzene[b/]	3.62	0.007	Yes	0.016	Yes	mg/kg
Toluene[b/]	37.7	1.7	Yes	4	Yes	mg/kg
Ethylbenzene[b/]	38.2	1.5	Yes	4	Yes	mg/kg
Xylenes (Total)[b/]	148	44	Yes	59.2	Yes	mg/kg
Naphthalene[b/]	11.8	0.2	Yes	24	No	mg/kg
Benzo(a)anthracene	0.171	0.7	No	0.56	No	mg/kg
Benzo(b)fluoranthene	0.056	0.66	No	3.2	No	mg/kg
Benzo(k)fluoranthene	0.026	4.6	No	3.2	No	mg/kg
Chrysene	0.064	0.66	No	0.8	No	mg/kg
Acenaphthene	0.726	-[c/]	-	160	No	mg/kg
Anthracene	0.188	-	-	3440	No	mg/kg
Benzo(a)pyrene	0.036	-	-	3.2	No	mg/kg
bis(2-Ethylhexyl)phthalate	5.07	-	-	8.8	No	mg/kg
Chlorobenzene[b/]	3.05	-	-	0.48	Yes	mg/kg
Fluoranthene	0.441	-	-	784	No	mg/kg
Fluorene	0.664	-	-	128	No	mg/kg
Pyrene	0.443	-	-	1120	No	mg/kg
1,3,5-Trimethylbenzene[b/]	47.4	-	-	0.208	Yes	mg/kg
2-Methylnaphthalene	16.1	-	-	-	-	mg/kg
Phenanthrene	0.604	-	-	-	-	mg/kg
1,2,3,4-Tetramethylbenzene	38.3	-	-	-	-	mg/kg
1,2,3-Trimethylbenzene	50.7	-	-	-	-	mg/kg
1,2,4-Trimethylbenzene	117	-	-	-	-	mg/kg

Sources: SCDHEC, 1995; USEPA Region III, 1995.
[a/]RBSL = risk-based screening level.
[b/]Analyte was retained for further evaluation if site concentration exceeds either SCDHEC (1995) or USEPA Region III (1996) criterion.
[c/]"-" = value not available.

TABLE 4.7
TIER 1 EVALUATION
COMPARISON OF SITE GROUNDWATER CONCENTRATIONS TO RBSLs
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	Detected Site Maximum Concentration	SCDHEC RBSL[a/]	Max. Conc. Exceeds SCDHEC RBSL	USEPA RBSL	Max. Conc. Exceeds USEPA RBSL	Units
Benzene[b/]	6900	5	Yes	0.36	Yes	µg/L
Toluene[b/]	10000	1000	Yes	750	Yes	µg/L
Ethylbenzene[b/]	2400	700	Yes	1300	Yes	µg/L
Xylenes (Total)	6100	10000	No	12000	No	µg/L
Naphthalene[b/]	270	25	Yes	1500	No	µg/L
Acenaphthene	1	-[c/]	-	2200	No	µg/L
Acetone	220	-	No	3,700	No	µg/L
Chlorobenzene[b/]	41	-	-	39	Yes	µg/L
1,1-Dichloroethane	1.4	-	-	810	No	µg/L
cis-1,2-Dichloroethene	120	-	-	61	Yes	µg/L
Diethylphthalate	9	-	-	29000	No	µg/L
2,4-Dimethylphenol	61	-	-	730	No	µg/L
Di-n-butylphthalate	1	-	-	3700	No	µg/L
Methylene Chloride	1	-	-	4.1	No	µg/L
2-Methylphenol(o-Cresol)	32	-	-	1800	No	µg/L
4-Methylphenol(p-Cresol)	45	-	-	180	No	µg/L
Phenol	5	-	-	22000	No	µg/L
Trichloroethene	0.8	-	-	1.6	No	µg/L
1,1,1-Trichloroethane	4	-	-	1300	No	µg/L
1,2,4-Trimethylbenzene[b/]	1400	-	-	300	Yes	µg/L
1,3,5-Trimethylbenzene[b/]	390	-	-	300	Yes	µg/L
2-Methylnaphthalene	120	-	-	-	-	µg/L
Phenanthrene	1	-	-	-	-	µg/L
1,2,3,4-Tetramethylbenzene	140	-	-	-	-	µg/L
1,2,3-Trimethylbenzene	400	-	-	-	-	µg/L

Sources: SCDHEC, 1995; USEPA Region III, 1995.
[a/]RBSL = risk-based screening level.
[b/]Analyte was retained for further evaluation if site concentration exceeds either SCDHEC (1995) or USEPA Region III (1996) criterion.
[c/]"-" = value not available.

TABLE 4.8
TIER 1 EVALUATION
COMPARISON OF SITE SOIL GAS CONCENTRATIONS TO INHALATION RBSLs
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Detected Analytes	Detected Site Maximum Concentration in Soil Gas	SCDHEC RBSL[a/] For Ambient Air	Max. Conc. Exceeds SCDHEC RBSL	USEPA RBSL For Ambient Air	Max. Conc. Exceeds USEPA RBSL	Units
Benzene[b/]	2,100,000	0.22	Yes	0.22	Yes	$\mu g/m^3$
Toluene[b/]	3,000,000	420	Yes	420	Yes	$\mu g/m^3$
Ethylbenzene[b/]	1,200,000	1,000	Yes	1,000	Yes	$\mu g/m^3$
Xylenes (Total)[b/]	4,100,000	730	Yes	7,300	Yes	$\mu g/m^3$

Sources: SCDHEC, 1995; USEPA Region III, 1995.
[a/]RBSL = risk-based screening level.
[b/]Analyte was retained for further evaluation if site concentration exceeds either SCDHEC (1995) or USEPA Region III (1996) criterion.

TABLE 4.9
LIST OF CHEMICALS OF POTENTIAL CONCERN
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Chemicals of Potential Concern	Rationale [a]
Soil	
Benzene	1995 risk-based average concentration > SCDHEC & USEPA risk-based leaching criterion
Toluene	1995 risk-based average concentration > SCDHEC & USEPA risk-based leaching criterion
Ethylbenzene	1995 risk-based average concentration > SCDHEC & USEPA risk-based leaching criterion
Xylenes (Total)	1995 risk-based average concentration > SCDHEC & USEPA risk-based leaching criterion
Naphthalene	1995 risk-based average concentration > SCDHEC risk-based leaching criterion
Chlorobenzene	1995 risk-based average concentration > USEPA risk-based leaching criterion
1,3,5-Trimethylbenzene	1995 risk-based average concentration > USEPA risk-based leaching criterion
Groundwater	
Benzene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Toluene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Ethylbenzene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Naphthalene	1995 risk-based maximum concentration > SCDHEC risk-based screening criterion
Chlorobenzene	1995 risk-based maximum concentration > USEPA risk-based screening criterion
1,2,4-Trimethylbenzene	1995 risk-based maximum concentration > USEPA risk-based screening criterion
1,3,5-Trimethylbenzene	1995 risk-based maximum concentration > USEPA risk-based screening criterion
cis-1,2-Dichloroethene	1995 risk-based maximum concentration > USEPA risk-based screening criterion
Air	
Benzene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Toluene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Ethylbenzene	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion
Xylenes (Total)	1995 risk-based maximum concentration > SCDHEC & USEPA risk-based screening criterion

[a] See Tables 4.5 through 4.8.

chlorobenzene, and 1,3,5-TMB are identified as the site COPCs in soil. These analytes are present in soils at concentrations high enough to potentially cause an exceedance of groundwater RBSLs. It is important to emphasize that soil concentrations did not exceed the RBSLs for ingestion of or dermal contact with soils under either a commercial or industrial scenario (Table 4.5). If a residential scenario had been determined appropriate, only the benzene maximum concentration would have exceeded the residential-based RBSL for ingestion or dermal exposure. Because benzene was determined to be a COPC based on soil-to-groundwater leachability concerns, the lack of a residential-based RBSL comparison has no impact on the final list of analytes retained as COPCs as a result of the Tier 1 screening analysis.

Based on comparisons of the maximum detected site chemical concentrations to the RBSLs for groundwater, benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and *cis*-1,2-dichloroethene (cis-DCE) are identified as the groundwater COPCs (Table 4.7). All of these except cis-DCE are fuel-related compounds thought to be directly associated with releases at Site ST-27. The compound cis-DCE is considered a COPC, although its source is not related to Site ST-27.

Based on comparisons of the maximum detected site soil gas concentrations (for BTEX compounds) to the RBSLs for the vapor inhalation exposure pathway, all BTEX compounds are identified as potential ambient air COPCs (Table 4.8). Because BTEX compounds were previously identified as COPCs, the issue of whether a comparison of soil gas concentrations (in place of absent soil flux or ambient air data) to the RBSLs for ambient air is overly conservative (health protective) or unreasonable is irrelevant for the following reason. These specific chemicals would have been retained for further Tier 2 analysis (for all media) had only a qualitative comparison been presented regarding potential contamination of air. This is because all BTEX compounds were identified as COPCs based on the Tier 1 evaluation for groundwater and/or soils. However, soil gas data presented in Table 4.8 do provide useful information or insight pertaining to nontoxic hazards posed by chronic exposure to these VOCs. Mainly, the Tier 1 analysis of soil gas data and ambient air RBSLs illustrate the relatively high concentrations of VOCs beneath the concrete apron. These concentrations could potentially represent an explosive hazard to Building 575 or subsurface utility systems in addition to the possibility of vapor exposure pathway. Explosive levels are evaluated and discussed in more detail in Section 5 of the CAP.

Only those analytes with site concentrations that exceeded the commercial/industrial soil RBSLs, the unrestricted use-based groundwater RBSLs, or the RBSLs for inhalation of soil vapors were retained for further analysis concerning the risk-reduction requirements for the site. The nature and extent of these contaminants are described more fully in Section 5. Quantitative fate and transport analyses and site-specific exposure estimates are conducted and presented in Sections 6 and 7 to develop site-specific Tier 2 target concentrations (i.e., SSTLs) that are sufficient to protect human health and the environment given the likely use of the land in question (i.e., industrial use only for Site ST-27 and areas immediately downgradient, and unrestricted use further downgradient and off-Base).

4.5 SITE PRIORITY CLASSIFICATION AND TIER 1 ACTION DECISION

Based upon the Tier 1 assessment and evaluation, Site ST-27 is classified as a Category 5 release. There is currently no demonstrable threat to human health or the environment, but the data indicate several analytes are present in soil and groundwater at concentrations that exceed their respective RBSLs. Therefore, further tier evaluation (at a minimum, Tier 2) is warranted (SCDHEC, 1995), and is presented in Sections 5 through 7.

SECTION 5

NATURE AND EXTENT OF CHEMICALS OF POTENTIAL CONCERN

5.1 OVERVIEW

This section summarizes the nature and extent of COPC contamination in soil and groundwater at and downgradient from Site ST-27 and adjacent SWMUs. Data from earlier site characterization activities (e.g., ES, 1983, 1993; GEL, 1988; Versar, Inc., 1991, 1992; EA, 1993; HNUS, 1993 and 1995) and the 1995 and 1996 risk-based remediation field investigations are included in this discussion. Discussion in this section is limited to only those chemicals that were identified as COPCs as a result of the Tier 1 screening analysis presented in Section 4 (i.e., BTEX, naphthalene, chlorobenzene, and 1,3,5-TMB in soil; benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB and cis-DCE in groundwater, and the BTEX compounds in air).

5.2 SOURCES OF CONTAMINATION

5.2.1 Underground Storage Tanks

Subsurface contamination at Site ST-27 is the result of leaking USTs. A former 3,000-gallon JP-4 jet fuel UST was confirmed to be leaking at the site in 1988. More recently, in January 1996, tracer leak testing indicated potential leaks from both the 4,000-gallon diesel and MOGAS USTs. The JP-4 jet fuel UST was located approximately 50 feet northeast of Building 575, underlying the fuel dispenser island. This tank was removed from service in January 1988, along with an adjacent 1,000-gallon UST used to store MOGAS. The first leak was confirmed during removal of the 3,000-gallon JP-4 jet fuel UST when LNAPL and visibly stained soils were encountered. No LNAPL or stained soils were encountered during the removal of the 1,000-gallon MOGAS UST. An attempt was made to excavate all soils with a flash point of less than 140°F during the UST removal operation (GEL, 1989). The leaking JP-4 jet fuel UST was identified as SWMU 145 in the Base-wide RCRA Part B permit (HNUS, 1993).

Subsequent to the 1988 removal operation, two 4,000-gallon fiberglass petroleum USTs, both installed in a membrane-lined pit, were installed in the same location as the former 3,000-gallon and 1,000-gallon USTs. A 10,000-gallon JP-4 jet fuel (later converted to JP-8 jet fuel) UST, enclosed within a subsurface concrete vault, was installed just northwest of the current location of the 4,000-gallon USTs. These new

USTs contribute to the total liquid fuel storage capacity required to meet Base mission and support requirements.

Tank integrity testing is performed on all three of these USTs on an annual basis. In early 1995, all three USTs and associated transfer lines were tested and passed. As presented earlier, during testing performed during the week of January 22, 1996, the petroleum UST systems associated with the two 4,000-gallon tanks failed a tracer leak test. Indications were that both MOGAS and diesel were leaking from the system. The MOGAS leak was traced to a bad pipeline coupling. No potential sources of the diesel release have been identified. The MOGAS UST and associated piping were removed from service after discovery of the release. The coupling of the transfer pipes has been replaced and the tank has been refilled with MOGAS. The diesel UST has not been removed from service; however, the tank has not been refilled since discovery of the potential release and this has effectively taken the system out of service. All USTs at the site are scheduled for removal in late 1997.

5.2.2 Adjacent SWMUs

The adjacent SWMUs 20 through 27 are part of the Building 575 oil/water separation system. A variety of cleaning agents, notably PD-680 solvent, striptone, alkali, varsol, and biodegradable soaps, have been used to wash equipment and aircraft at SWMU 20 (Building 575 wash rack) (HNUS, 1993). PD-680 is a petroleum-based cleaning agent. As noted previously, striptone is comprised primarily of methylene chloride (which, although detected in groundwater samples collected near SWMU 20, was not identified as a COPC as a result of the Tier 1 analysis). The washrack itself consists of concrete slabs separated by construction and expansion joints. Some of these joints are more than 0.75 inch wide, which may be sufficient to allow wastewater from the washrack to percolate into underlying soils and groundwater. The impact of former operations at these adjacent SWMUs on soil and groundwater quality at downgradient Site ST-27 is incorporated into this CAP.

5.3 SOIL GAS SAMPLING RESULTS

Soil gas samples collected at Site ST-27 during the 1993 bioventing pilot test soil gas sampling and the 1995 risk-based remediation field effort were analyzed for individual BTEX compounds and TVH. Soil gas samples were used for secondary confirmation of the nature and extent of unsaturated soil contamination at a site. Soil gas samples were used to obtain a better representation of soil contamination because the samples are extracted from a larger volume of soil than a discrete soil sample collected with a splitspoon. Discrete soil samples are usually nonhomogeneous, and analytical results can vary greatly between subsamples collected from the same splitspoon. Thus, soil gas samples provide a valuable indication of the type and magnitude of VOC contamination in the soil.

Figure 5.1 presents the analytical soil gas results for BTEX by sampling location for samples collected at Site ST-27 in 1993 and 1995. Benzene was detected in all six of the soil gas samples collected from ST-27. Soil gas concentrations of benzene ranged from 57 parts per million, volume per volume (ppmv) at MPC [which is equivalent to

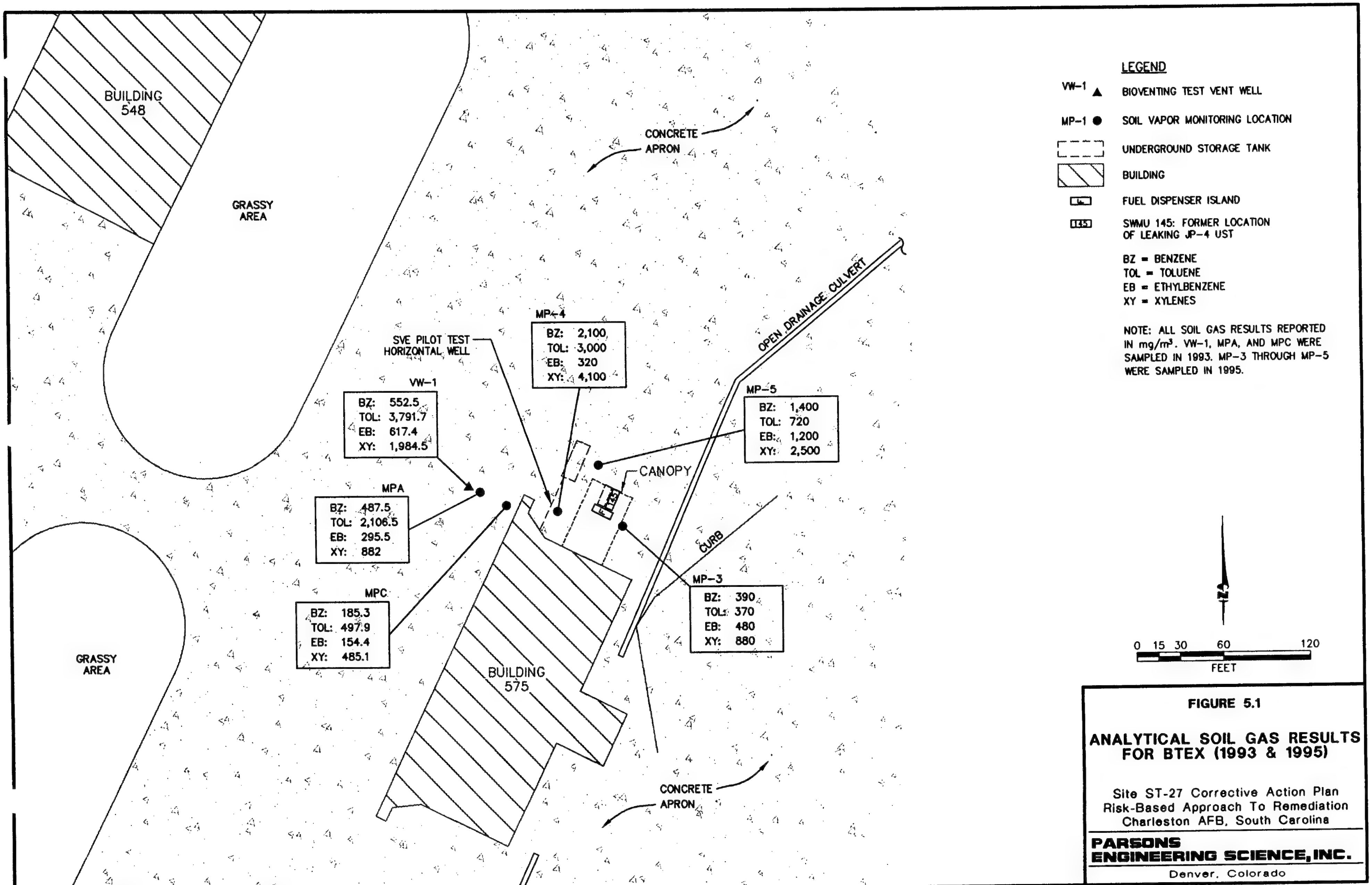

FIGURE 5.1

ANALYTICAL SOIL GAS RESULTS FOR BTEX (1993 & 1995)

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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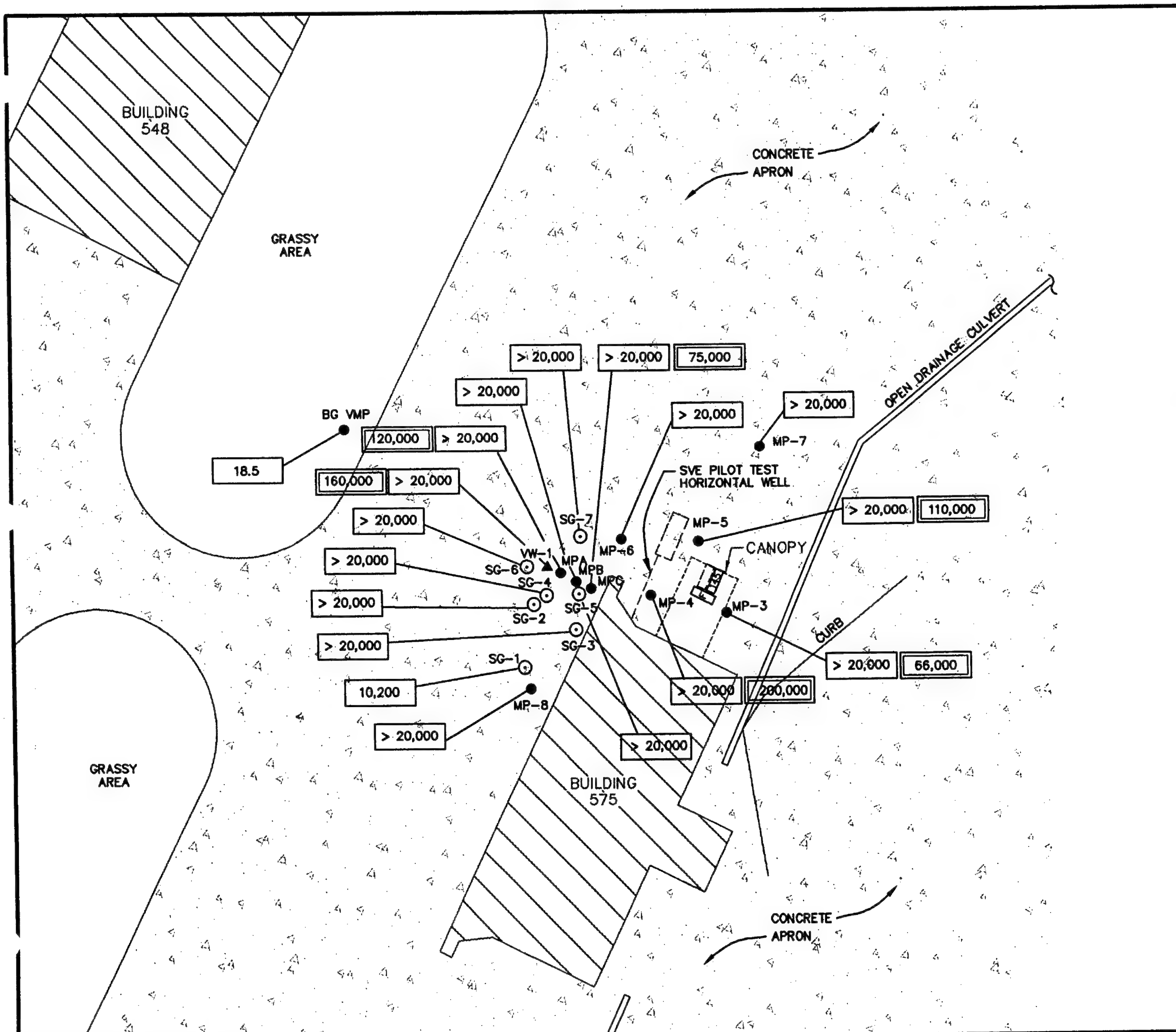
185 milligrams per cubic meter (mg/m^3)] to 660 ppmv (2,100 mg/m^3) at MP-4. All measured concentrations of benzene in soil gas significantly exceeded the time-weighted-average (TWA) 8-hour permissible exposure limit (PEL) of 3.25 mg/m^3 defined for benzene by the Occupational Safety and Health Administration (OSHA, 1995). Soil gas concentrations of toluene ranged from 97 ppmv (370 mg/m^3) to 990 ppmv (3,792 mg/m^3). All but the lowest measured concentration of toluene in soil gas significantly exceeded the TWA 8-hour PEL of 375 mg/m^3 defined for toluene by OSHA (1995). Soil gas concentrations of ethylbenzene ranged from 35 ppmv (154 mg/m^3) to 280 ppmv (1,200 mg/m^3). Three of the six soil gas samples contained ethylbenzene at concentrations above the TWA 8-hour PEL of 435 mg/m^3 defined for ethylbenzene by OSHA (1995). Soil gas concentrations of xylenes ranged from 110 ppmv (485 mg/m^3) to 920 ppmv (4,100 mg/m^3). All of the six soil gas samples contained total xylene at concentrations above the TWA 8-hour PEL of 435 mg/m^3 defined for total xylene by OSHA (1995).

Figure 5.2 presents the TVH soil gas sampling results for samples collected at Site ST-27 as part of the 1993 bioventing pilot test soil gas sampling and the 1995 risk-based remediation investigation. TVH concentrations measured in all the collected soil gas samples were elevated. All measured TVH concentrations were greater than 2 percent by volume in the soil gas. The lower explosive limits (LELs) for MOGAS and JP-4 jet fuel are 1.4 and 1.3 percent by volume, respectively. The concentrations of volatile hydrocarbons in the soil gas at Site ST-27 are greater than the LELs and could pose an explosive risk.

The TVH data, when coupled with the compound-specific soil gas data (Figure 5.1), indicate residual soil contamination adjacent to and immediately downgradient from the past and present USTs. This means that if future excavation of these soils proves necessary to support remedial or construction activities, appropriate air monitoring and personal protective equipment will be necessary at a minimum to ensure that soil gas concentrations do not pose a potential risk to workers. The remedial requirements driven by this type of site contamination are considered further in Sections 8, 9, and 10 of this CAP.

5.4 SOIL SAMPLING RESULTS

Prior to 1995 sampling events (i.e., both the risk-based investigation conducted at Site ST-27 and the HNUS sampling event conducted at adjacent SWMUs), soil analytical data were not extensive, especially for soils in the immediate vicinity of the former 3,000-gallon JP-4 jet fuel UST. Historically, only nine soil samples had been analyzed for petroleum hydrocarbon constituents prior to 1995. Three of the nine soil samples were collected by ES (1993) in the bioventing pilot study area. The remaining six soil samples were collected during installation of permanent groundwater monitoring wells. Collectively, soil samples at Site ST-27 have been analyzed for TRPH, TPH (gasoline and jet fuel fractions), VOCs including the BTEX compounds, SVOCs, and metals. The fuel-related compounds identified as soil COPCs as a result of the Tier 1 analysis include the BTEX compounds, naphthalene, chlorobenzene, and 1,3,5-TMB. No compounds were measured in soil samples collected at this site at concentrations above the applicable health-protective Tier 1 criteria.



LEGEND

- VW-1 ▲ BIOVENTING TEST VENT WELL
- SG-1 ⊙ TEMPORARY SOIL GAS MONITORING LOCATION (SAMPLED 1993)
- MP-1 ● SOIL VAPOR MONITORING POINT (PERMANENT) (SAMPLED 1995)
- UNDERGROUND STORAGE TANK
- BUILDING
- FUEL DISPENSER ISLAND
- 145 SWMU 145: FORMER LOCATION OF LEAKING JP-4 UST
- > 20,000 TVH FIELD SCREENING RESULT (ppm)
- 66,000 TVH LABORATORY ANALYTICAL RESULTS (ppmv)

NOTE: VW-1, MPA, MPB, MPC, BG VMP, AND ALL SG's WERE SAMPLED IN 1993. MP-3 THROUGH MP-8 WERE SAMPLED IN 1995.

NOTE: TVH FIELD SCREENING RESULTS (ppm) OBTAINED WITH A PORTABLE TOTAL HYDROCABON ANALYZER

0 15 30 60 120
FEET

FIGURE 5.2

TVH SOIL GAS SAMPLING RESULTS (1993 & 1995)

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

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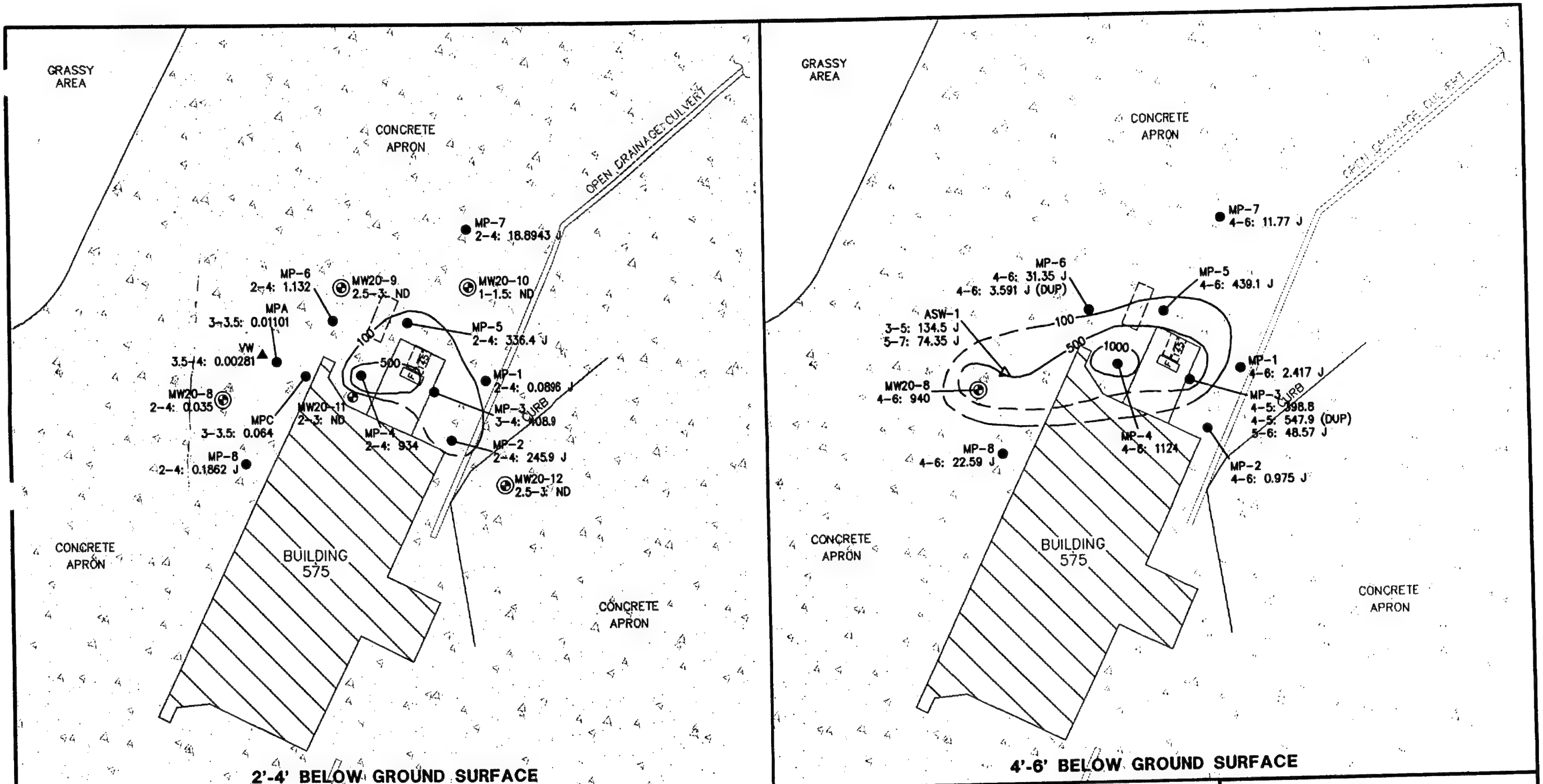
Available soil analytical data indicate that soil COPCs are generally not elevated in shallow, unsaturated soils. To illustrate, Figure 5.3 presents all the analytical data for total BTEX in soil samples collected from 2 to 4 feet bgs within the thin vadose zone at this site. In addition to data collected during the 1995 risk-based investigation, soil data collected during the 1990 RI (Versar, Inc., 1992), the 1993 supplemental groundwater investigation (EA, 1993), and the 1993 bioventing pilot test (ES, 1993) are included on this figure. The only elevated concentrations of total BTEX in unsaturated soils were measured adjacent to the location of the former 3,000-gallon JP-4 jet fuel UST and SWMU 21, the washrack. The presence of elevated concentrations of BTEX compounds in shallow soils adjacent to the washrack is consistent with the operational history of this site. Wastewater that contained PD-680 solvent or fuel hydrocarbons washed from the aircraft likely percolated through the cracked surface of the washrack into underlying shallow soils.

In comparison, Figure 5.3 also shows that the BTEX compounds were detected more frequently and at higher concentrations in soil samples collected from the capillary fringe at 4 to 7 feet bgs. Elevated concentrations of total BTEX in soil were measured in all the deeper-interval samples collected adjacent to and downgradient from the location of the old and new USTs. These data further confirm that the significant source of soil contamination at Site ST-27 was leaking USTs and associated piping, which probably released a portion of the fuel into saturated subsurface soils because the tank was installed below the water table.

Figure 5.4 presents the maximum concentrations of the soil COPCs measured at each of the soil sampling locations. Isoconcentration contours developed using these maximum data are shown as well to define the areal extent of soil COPCs at the site. These data indicate that soil contamination is centered near the northern side of Building 575, adjacent to the former location of the 3,000-gallon JP-4 jet fuel UST. The maximum total BTEX concentration of 1,124 mg/kg was detected at MP-4 at a depth of 4 to 6 feet bgs. The maximum concentrations of benzene (34 mg/kg), toluene (320 mg/kg), ethylbenzene (150 mg/kg), and xylenes (620 mg/kg) detected at this site in soil were measured at this soil sampling location. The maximum concentration of chlorobenzene (21 mg/kg) also was measured at this sampling location. The maximum concentration of both naphthalene (48 mg/kg) and 1,3,5-TMB (162 mg/kg) were measured at MP-3, which is less than 50 feet southeast of MP-4 at the southeastern corner of the former location of the 3,000-gallon JP-4 jet fuel UST. The soil analytical data indicate that about 80,000 square feet (ft^2), or 1.8 acres, may be impacted by measurable concentrations of at least one of the soil COPCs. However, the highest concentrations of the soil COPCs appear to be limited to about an 11,000-ft^2 or 0.25-acre plot of land immediately to the northeast of Building 575. All of the analytical soil results from the 1995 risk-based investigation are presented in Appendix A.

5.5 GROUNDWATER SAMPLING RESULTS

The following section summarizes the results of groundwater sampling events conducted during previous site investigations, and fully characterizes the extent of groundwater COPCs as defined during the 1995 and 1996 focused field investigation in support of a risk-based remediation of Site ST-27. Benzene, toluene, ethylbenzene,



LEGEND

MW20-8 ◉	GROUNDWATER MONITORING WELL (INSTALLED 1990 OR 1993)
VW ▲	VENT WELL
ASW-1 △	AIR SPARGING TEST WELL
MP-6 ● 2-4: 1.132	SOIL SAMPLING LOCATION DEPTH INTERVAL (FT BGS): TOTAL BTEX CONCENTRATION (mg/kg)
J	ESTIMATED VALUE
ND	ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
[FL]	FUEL DISPENSER ISLAND
145	SWMU 145: FORMER LOCATION OF LEAKING JP-4 UST
[- - -]	UNDERGROUND STORAGE TANK
—500—	LINE OF ESTIMATED EQUAL TOTAL BTEX CONCENTRATION IN SOILS (mg/kg) (DASHED WHERE INFERRED) CONTOURS BASED ON HIGHEST CONCENTRATIONS DETECTED AT SAMPLING LOCATIONS

NOTE: CONTOURS BASED ON HIGHEST CONCENTRATIONS DETECTED AT SAMPLING LOCATIONS.

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FIGURE 5.3

SOIL BTEX CONCENTRATIONS

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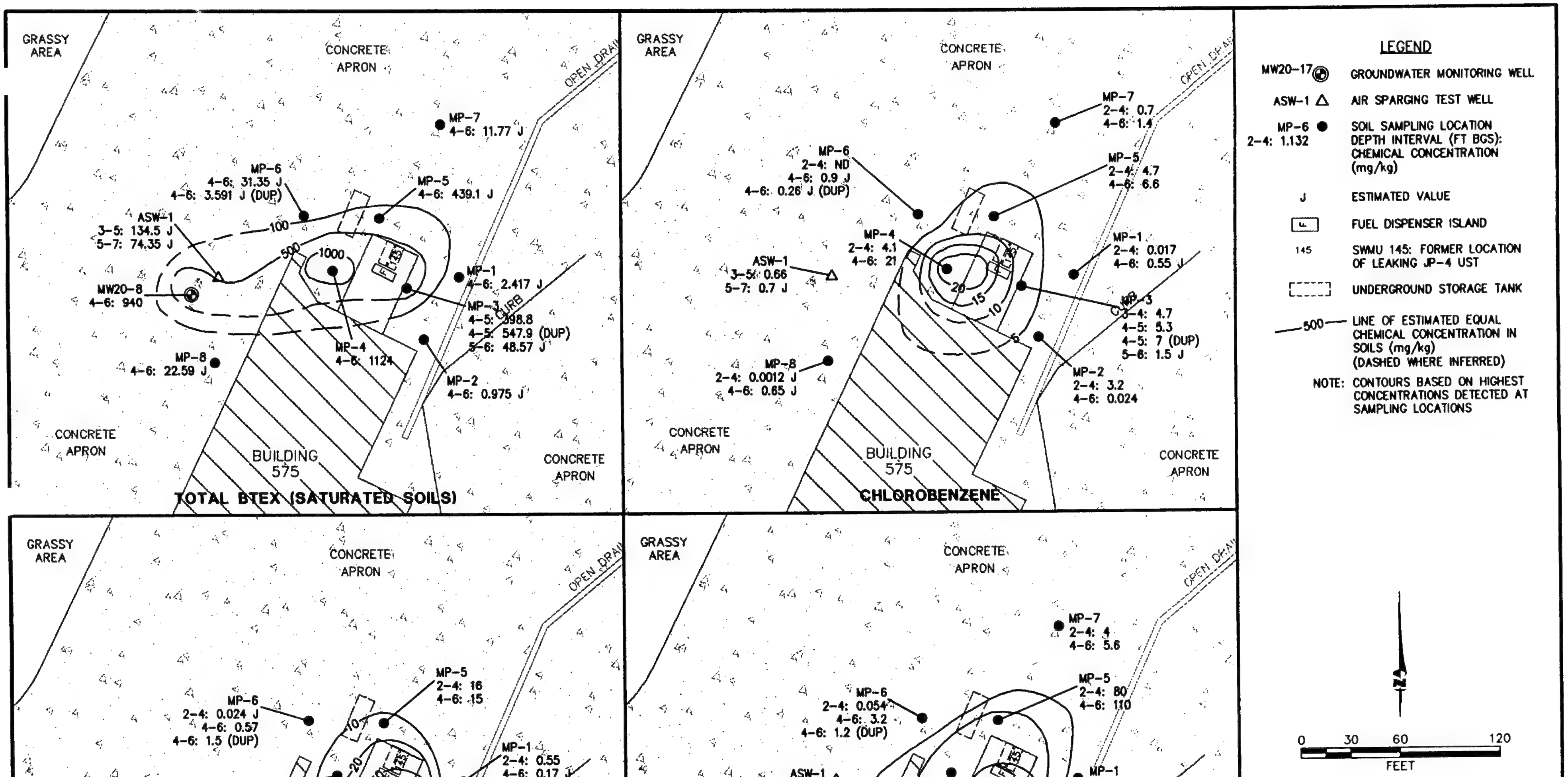

FIGURE 5.4

OTHER COPCS SOIL CONCENTRATIONS

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chlorobenzene, naphthalene, 1,2,4-TMB, 1,3,5-TMB, and cis-DCE were identified as groundwater COPCs based on the Tier 1 analysis presented in Section 4. This section fully describes the extent of groundwater COPCs only. All 1995 and 1996 analytical results for groundwater are presented in Appendix A.

As described in Section 3, the saturated thickness of the shallowest water-bearing zone within the Ladson Formation underlying Site ST-27 varies from about 32 to 34 feet before the confining Cooper Formation is encountered. Most permanent groundwater monitoring wells at Site ST-27 are screened from about 4 to 12 feet bgs, which is across the upper few feet of the shallow aquifer. However, two deep wells have been installed at the site to assess the vertical distribution of chemical contamination in the Ladson Formation aquifer. Well MW20-18, which was installed as part of the 1995 risk-based investigation, is a nested shallow (MW20-18S) and deep (MW20-18D) well, with the deep screen set at 27 to 32 feet bgs. Well MW20-8 is a deep well with the screen set from 23 to 32 feet bgs (Versar, Inc., 1992).

5.5.1 LNAPL

LNAPL thicknesses or visible oily sheens have been measured in three permanent groundwater monitoring wells installed adjacent to and downgradient from the former leaking USTs at Site ST-27 (i.e., wells MW20-1, MW20-3, and MW20-5). Monitoring well MW20-1 is located about 25 feet southeast of the past and present location of the USTs; monitoring well MW20-3 is located about 120 feet southwest of the UST location; and monitoring well MW20-5 is located approximately 55 feet northeast of the location of USTs (see Figures 2.3). During the initial site investigation in 1988 following tank removal, no measureable thicknesses of LNAPL were observed in the installed groundwater monitoring wells at the site, though an oily sheen was observed on the surface of groundwater samples collected from MW20-1 and MW20-3 (GEL, 1988). By 1990, however, a measurable LNAPL thickness (i.e., > 0.05 foot) was observed at well MW20-1 (Versar, Inc., 1992). No LNAPL or oily sheen was observed at well MW20-3. Measurable LNAPL was again observed at well MW20-1 during a 1992 field inspection conducted by HNUS (1993) in anticipation of supplemental site work. By 1993, measurable LNAPL thicknesses were detected at wells MW20-1 and MW20-5 (EA, 1993). Approximately 0.10 foot of LNAPL was measured at well MW20-1, and 0.05 foot of LNAPL was measured at well MW20-5 during this sampling event. LNAPL again was measured in wells MW20-1 and MW20-5 during the 1995 risk-based investigation. LNAPL thicknesses observed in these two wells in 1995 were greater than those measured during the 1993 investigation. Approximately 0.20 foot of LNAPL was measured at well MW20-1, and about 0.15 foot of LNAPL was observed at well MW20-5. LNAPL was not observed at well MW20-3.

Samples of LNAPL were collected from both well MW20-1 and well MW20-5 during the 1995 risk-based investigation and submitted for chemical analysis. Table 5.1 compares analytical data for the specific BTEX compounds for these LNAPL samples to the range of concentrations of the same compounds typically found in "fresh" (unweathered) JP-4 jet fuel and MOGAS. The concentrations of BTEX observed in the two recently collected LNAPL samples all fall within or are greater

TABLE 5.1
CHEMICAL ANALYSIS OF LNAPL SAMPLES
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Compounds	Reported Concentration in LNAPL from MW20-1 (8/95) (mg/L)	Reported Concentration in LNAPL from MW20-5 (8/95) (mg/L)	Range of Concentrations in "Fresh" JP-4 Jet Fuel[a/] (mg/L)	Range of Concentrations in "Fresh" MOGAS[a/] (mg/L)
Benzene	1,400,000	1,500,000	82,500 - 3,750,000	6,589,000 - 28,552,000
Toluene	2,300,000	2,900,000	219,450 - 9,975,000	32,945,000 - 47,586,000
Ethylbenzene	4,900,000	6,700,000	611,000 - 2,775,000	8,785,000 - 10,249,000
Total xylenes	15,000,000	84,000,000	379,500 - 17,400,000	40,998,000 - 64,425,000

[a/] Arthur D. Little, Inc., 1985; Martel, 1987; ES, 1994b.

than the range of BTEX concentrations typically observed in "fresh" JP-4 and are generally below concentrations observed in "fresh" MOGAS. The concentration of total xylenes observed in the LNAPL sample collected from MW20-5 exceeded the typical xylene concentration in MOGAS.

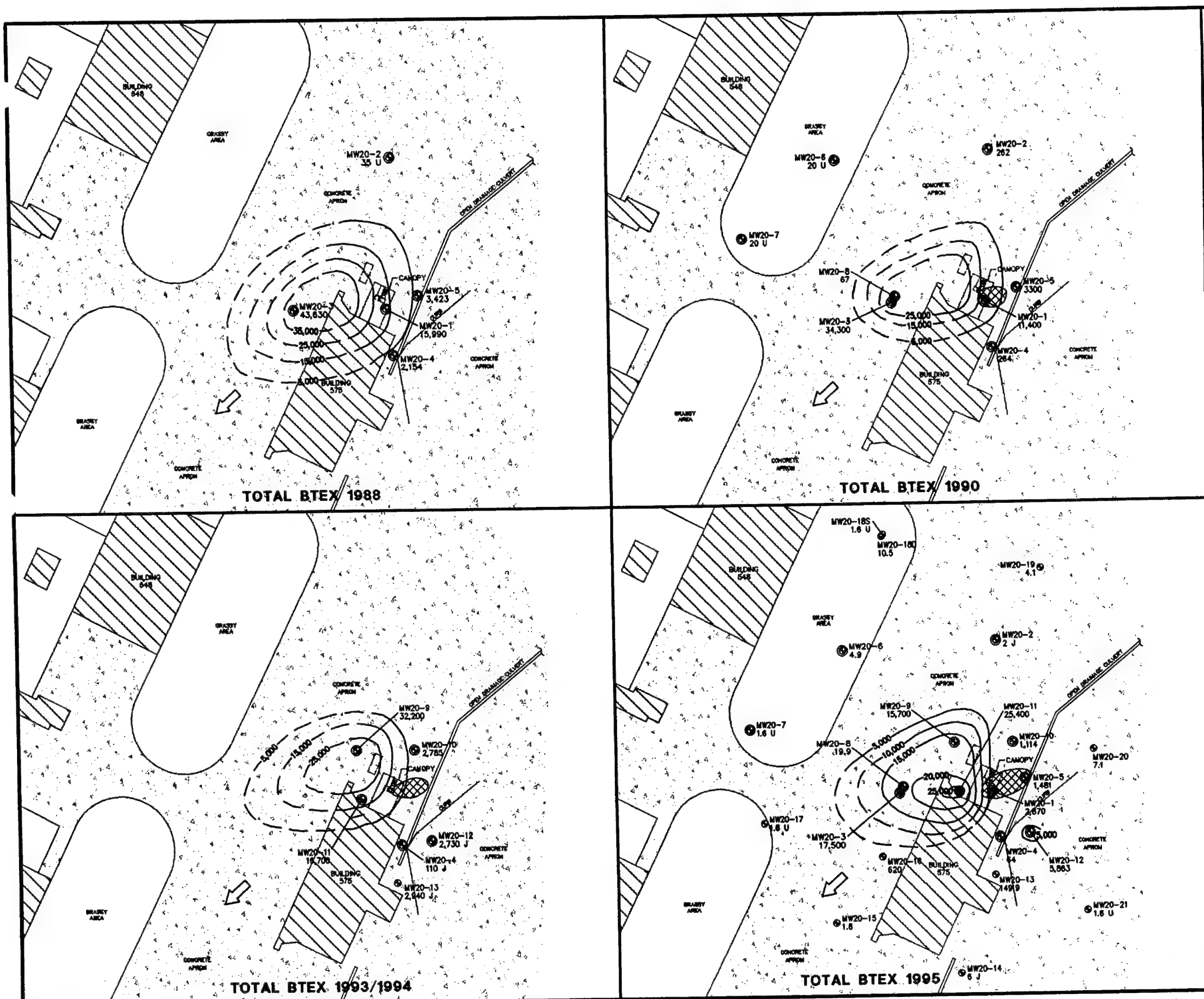
Site history, hydrogeological data, and LNAPL thickness data can be used to support two general hypotheses about LNAPL contamination and migration at Site ST-27. First, the apparent behavior of the LNAPL in the subsurface may be the result of slow groundwater movement and the lack of a significant hydraulic gradient at the site. The differences in measured LNAPL thicknesses over time could also be the result of seasonal changes in groundwater elevation at Site ST-27. Seasonal fluctuations in groundwater elevations, and its effects on LNAPL thickness further supports the suggestion that much of the fuel was released below the water table surface from the original leaking JP-4 UST. Migration of LNAPL at the site may also be due to dispersion as product spreads across the nearly flat groundwater surface at the site. As discussed in Section 3, although the groundwater generally flows toward the southwest, seasonal water level data indicate that groundwater can also flow toward the northeast and west at the site. These seasonal changes in flow direction may be indirectly affecting LNAPL migration in the subsurface.

The second hypothesis about the nature of LNAPL contamination and migration at the site is significantly different from the first hypothesis. It is probable that the LNAPL detected in 1990 originated from a different chemical source than the LNAPL detected in 1995. As discussed in Section 1.3.1, tank integrity testing performed in January 1996 indicated that both MOGAS and diesel fuel have been released at the site. This could potentially explain the increase in LNAPL thicknesses measured in 1995, as well as the high concentrations of BTEX detected in LNAPL samples.

5.5.2 Shallow Dissolved Contamination

Shallow groundwater contamination was detected at Site ST-27 in June 1988 during the initial hydrogeologic investigation conducted following the tank removal (GEL, 1988). Groundwater samples were collected and analyzed for the individual BTEX compounds, lead, and other field parameters such as temperature and specific conductance. Groundwater samples were not analyzed for any of the other groundwater COPCs during this sampling event. Of the five groundwater wells installed and sampled as part of this effort (i.e., wells MW20-1 through MW20-5), MW20-2 is the only well in which at least one of the BTEX compounds was not detected (Figure 5.5). A maximum concentration of benzene of 5,120 μg/L was measured at well MW20-3 in June 1988. Maximum concentrations of toluene (24,000 μg/L) and ethylbenzene (2,110 μg/L) also were measured at this sampling location. Total dissolved BTEX results from this sampling event are presented on Figure 5.5. The 1988 analytical results for each of the BTEX compounds that are groundwater COPCs are presented in Table 5.2.

Following confirmation of groundwater contamination, Site ST-27 was identified as an IRP site and investigated as part of the Base-wide 1990 RI (Versar, Inc., 1992). Groundwater samples were collected from the five existing wells and from three newly



LEGEND

MW20-1 619	GROUNDWATER MONITORING WELL WITH BTEX CONCENTRATION (µg/L) (INSTALLED 1988, 1990, OR 1993)
MW20-17 620	GROUNDWATER MONITORING WELL WITH BTEX CONCENTRATION (µg/L) (INSTALLED 1995)
	UNDERGROUND STORAGE TANK
	BUILDING
	FUEL DISPENSER ISLAND
145	SWMU 145: FORMER LOCATION OF LEAKING JP-4 UST
—5,000—	LINE OF ESTIMATED EQUAL TOTAL BTEX CONCENTRATIONS IN IN GROUNDWATER (µg/L) (DASHED WHERE INFERRED)
	CONTOURS BASED ON HIGHEST CONCENTRATIONS DETECTED AT SAMPLING LOCATIONS
	EXTENT OF LNAPL
U	ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
J	ESTIMATED VALUE
	GENERALIZED GROUNDWATER FLOW DIRECTION

NOTE: MW20-8 AND MW20-18D ARE DEEP WELLS AND WERE NOT CONSIDERED IN CONTOURS.

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FIGURE 5.5

TOTAL BTEX CONCENTRATIONS IN GROUNDWATER

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TABLE 5.2
HISTORICAL TRENDS IN GROUNDWATER COPCs
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

BENZENE					
Sampling Location	1988 Results (µg/L)	1990 Results (µg/L)	1993 Results (µg/L)	1994 Results (µg/L)	1995 Results (µg/L)
MW20-1	2450	2800			980
MW20-2	< 5	19			ND
MW20-3	5120	4000			2000
MW20-4	188	19		ND (100) [a/]	9
MW20-5	868	270			160
MW20-6		ND			ND
MW20-7		ND			ND
MW20-8		ND			7.7
MW20-9			6100		3900
MW20-10			1800		740
MW20-11			5900		6900
MW20-12			170	1700	610
MW20-13				1800	89

TOLUENE					
Sampling Location	1988 Results (µg/L)	1990 Results (µg/L)	1993 Results (µg/L)	1994 Results (µg/L)	1995 Results (µg/L)
MW20-1	5770	2000			86
MW20-2	< 10	21			0.6 J [b/]
MW20-3	24000	18000			8800
MW20-4	344	21		ND (100)	5
MW20-5	85	ND			51
MW20-6		ND			1.6
MW20-7		ND			ND
MW20-8		15			2.4
MW20-9			16000		7800
MW20-10			9		24
MW20-11			6100		10000
MW20-12			2 J	360 J	56
MW20-13				22 J	41

ETHYLBENZENE					
Sampling Location	1988 Results (µg/L)	1990 Results (µg/L)	1993 Results (µg/L)	1994 Results (µg/L)	1995 Results (µg/L)
MW20-1	1110	1200			890
MW20-2	< 10	140			ND
MW20-3	2110	2600			1600
MW20-4	644	140		ND (100)	40
MW20-5	520	990			610
MW20-6		ND			ND
MW20-7		ND			ND
MW20-8		4			2.4
MW20-9			2400		1100
MW20-10			880		300
MW20-11			1500		2400
MW20-12			43	440 J	97
MW20-13				860 J	7.9

NAPHTHALENE				
Sampling Location	1990 Results (µg/L)	1993 Results (µg/L)	1994 Results (µg/L)	1995 Results (µg/L)
MW20-1	210			270
MW20-3	190			210
MW20-4			45	
MW20-9		280		230
MW20-10		270		240
MW20-11		240		270
MW20-12		24	75	29
MW20-13			ND (7)	11

a/ ND (100) = Analyte reported not detected above method detection limit of 100 µg/L.
b/ J = Estimated value.

022/725526/13.XLS/TABLE 5.2

installed wells (wells MW20-6, MW20-7, and MW20-8) during the August 1990 sampling event. The maximum concentration of benzene (4,000 µg/L) in groundwater was again detected at well MW20-3, although at a concentration about 22 percent of the concentration measured during the June 1988 sampling event. Comparable reductions in the concentrations of the other BTEX compounds were observed. Low concentrations of cis-DCE (10 µg/L) were detected in groundwater samples from MW20-2 and MW20-4. None of the BTEX compounds or cis-DCE were detected in deep well MW20-8 during this sampling event. Sampling results for the remaining groundwater COPCs (i.e., naphthalene, chlorobenzene, 1,2,4-TMB, and 1,3,5-TMB) were not reported in the available site data. BTEX results from this sampling event are presented on Figure 5.5. The 1990 analytical results for each of the BTEX compounds that are groundwater COPCs also are presented in Table 5.2.

A supplemental groundwater investigation was performed in May and June 1993 (EA, 1993). Four new permanent groundwater monitoring wells were installed and sampled (i.e., wells MW20-9 through MW20-12). None of the existing wells were resampled during this field event. Elevated concentrations of the groundwater COPCs benzene, toluene, ethylbenzene, and naphthalene were measured in all four of the new wells. Analytical data on the other groundwater COPCs were not reported in available site data. A maximum benzene concentration of 6,100 µg/L was measured in well MW20-9, which is about 100 feet northeast of well MW20-3 (Figure 5.5). Maximum concentrations of toluene (16,000 µg/L), ethylbenzene (2,400 µg/L), and naphthalene (280 µg/L) were also measured at this sampling location in June 1993. Total BTEX results from this sampling event are presented on Figure 5.5. The 1993 analytical results for each of the BTEX compounds that are groundwater COPCs and naphthalene also are presented in Table 5.2.

A RFI was conducted at the adjacent SWMUs in July 1994 (HNUS, 1995). Groundwater samples were collected from two existing wells (i.e., wells MW20-4 and MW20-12) and newly installed well MW20-13 as part of this field investigation. Well MW20-12 is located about 40 feet northeast of well MW20-4, and new well MW20-13 was installed approximately 50 feet southwest of well MW20-4 (Figure 5.5). Analytical data for the BTEX compounds and naphthalene were collected at the three sampling locations. A maximum benzene concentration of 1,800 µg/L was detected in well MW20-13. Benzene was detected in well MW20-12 at a concentration of 1,700 µg/L, but apparently was not detected in well MW20-4 at a reporting limit of 100 µg/L. The maximum toluene concentration of 360 µg/L was detected at well MW20-12, and the maximum ethylbenzene concentration of 860 µg/L was detected at well MW20-13. Naphthalene also was detected in two of the three wells sampled in July 1994. Naphthalene was detected at a concentration of 75 µg/L at well MW20-12, and at a concentration of 45 µg/L at well MW20-4. No naphthalene was detected at well MW20-13 at a reporting limit of 7 µg/L. The analytical results for each of the groundwater COPCs measured in July 1994 are presented in Table 5.2. Sampling results for the remaining groundwater COPCs (i.e., chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and cis-DCE) were not reported in the available site data.

Groundwater samples were collected from existing wells MW20-1 through MW20-13 and newly-installed wells MW20-14 through MW20-21 in August 1995 and January

1996 as part of the risk-based remediation field investigation. Elevated concentrations of benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB and cis-DCE were measured in at least 3 of the 21 wells sampled. The maximum concentration of benzene of 6,900 µg/L was detected in well MW20-11 during the 1995/96 sampling event (Figure 5.6). Analytical results for groundwater samples collected in 1995/96 from wells that had been previously sampled indicate that benzene concentrations have been reduced at individual sampling locations by an average of approximately 25 percent since 1993 and 50 percent since 1988 (Table 5.2). The maximum concentrations of toluene (10,000 µg/L) and ethylbenzene (2,400 µg/L) were also measured at well MW20-11 during the 1995/96 sampling event (Figure 5.6). The toluene concentration at this well in 1995/96 is about 40 percent greater than that measured in 1993 (6,100 µg/L). The concentration of ethylbenzene at this sampling location also showed an increase of about 38 percent since the 1993 sampling event (1,500 µg/L). This increase in contaminant concentrations is restricted to wells in the immediate vicinity of the leaking UST and/or pipeline discovered in January 1996. Therefore, the detected increases in COPCs in these wells is probably directly attributable to the new release. All other wells that have been sampled at least twice since 1988 (see Table 5.2), have experienced decreases in both toluene and ethylbenzene concentrations over time. The extent of total BTEX in groundwater, as defined by the 1995/96 sampling event, is compared to historical groundwater sampling results in Figure 5.5. Figures 5.6 and 5.7 present the isoconcentration contours based on 1995/96 analytical results for each of the groundwater COPCs. Based on the 1995/96 analytical results, an area of about 88,400 ft^2 or 2 acres is impacted with measurable levels of groundwater COPCs.

Naphthalene also was identified as a groundwater COPC as a result of the Tier 1 analysis. Naphthalene was a target compound of the 1990 RI (Versar, Inc., 1991), the 1993 supplemental groundwater investigation (EA, 1993), the 1994 RFI (HNUS, 1995), and the 1995/96 risk-based investigation. The maximum concentration of naphthalene detected at Site ST-27 (270 µg/L) was measured at wells MW20-1 and MW20-11 during the 1995/96 sampling event. Previously, naphthalene had been detected at well MW20-1 in 1990 at a concentration of 210 µg/L, and at well MW20-11 in 1993 at a concentration of 240 µg/L (Table 5.2). No naphthalene was detected in either of the two deep wells at this site. Figure 5.7 shows the estimated extent of naphthalene in groundwater at Site ST-27 based on 1995/96 sampling results. These data indicate that naphthalene contamination impacts an area roughly equivalent to that impacted by BTEX contamination.

The extent of the remaining groundwater COPCs (chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and cis-DCE), based on 1995/96 sampling results, is presented in Figure 5.7. Limited historical data on these other COPCs precludes any observable trend in contaminant concentrations, and this discussion is restricted to the current risk-based investigation results. The maximum concentration of chlorobenzene observed during the 1995 investigation, 41 µg/L, was measured at well MW20-9. Chlorobenzene was detected in 7 of the 21 wells sampled in 1995/96. The maximum concentrations of 1,2,4-TMB (1,400 µg/L) and 1,3,5-TMB (390 µg/L) were detected in well MW20-3. The TMB isomers were detected in at least 10 of the 21 wells sampled during the 1995/96 field effort. The maximum concentration of cis-DCE (120 µg/L) was detected

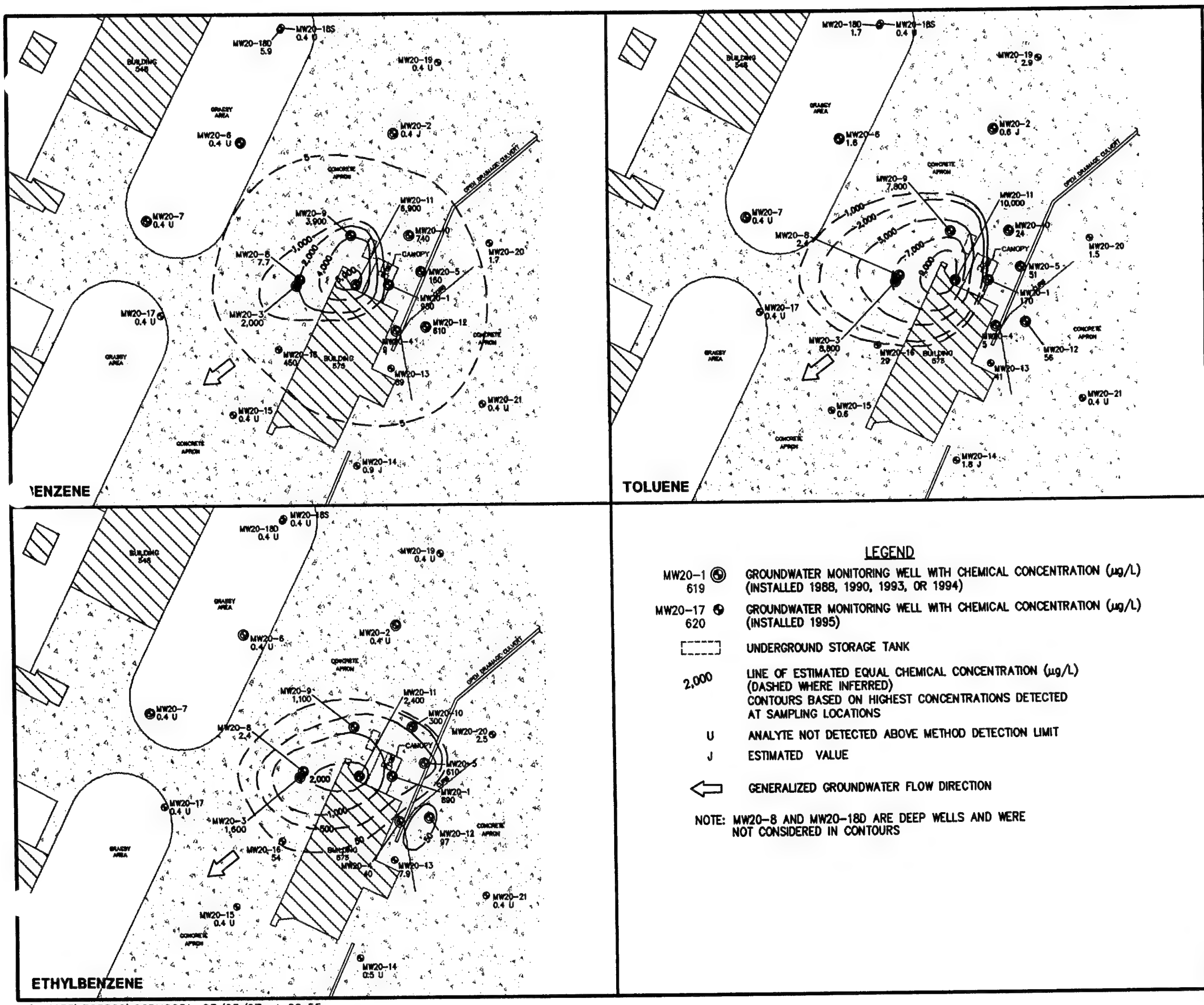

FIGURE 5.6

1995 BENZENE, TOLUENE, AND ETHYLBENZENE CONCENTRATIONS IN GROUNDWATER

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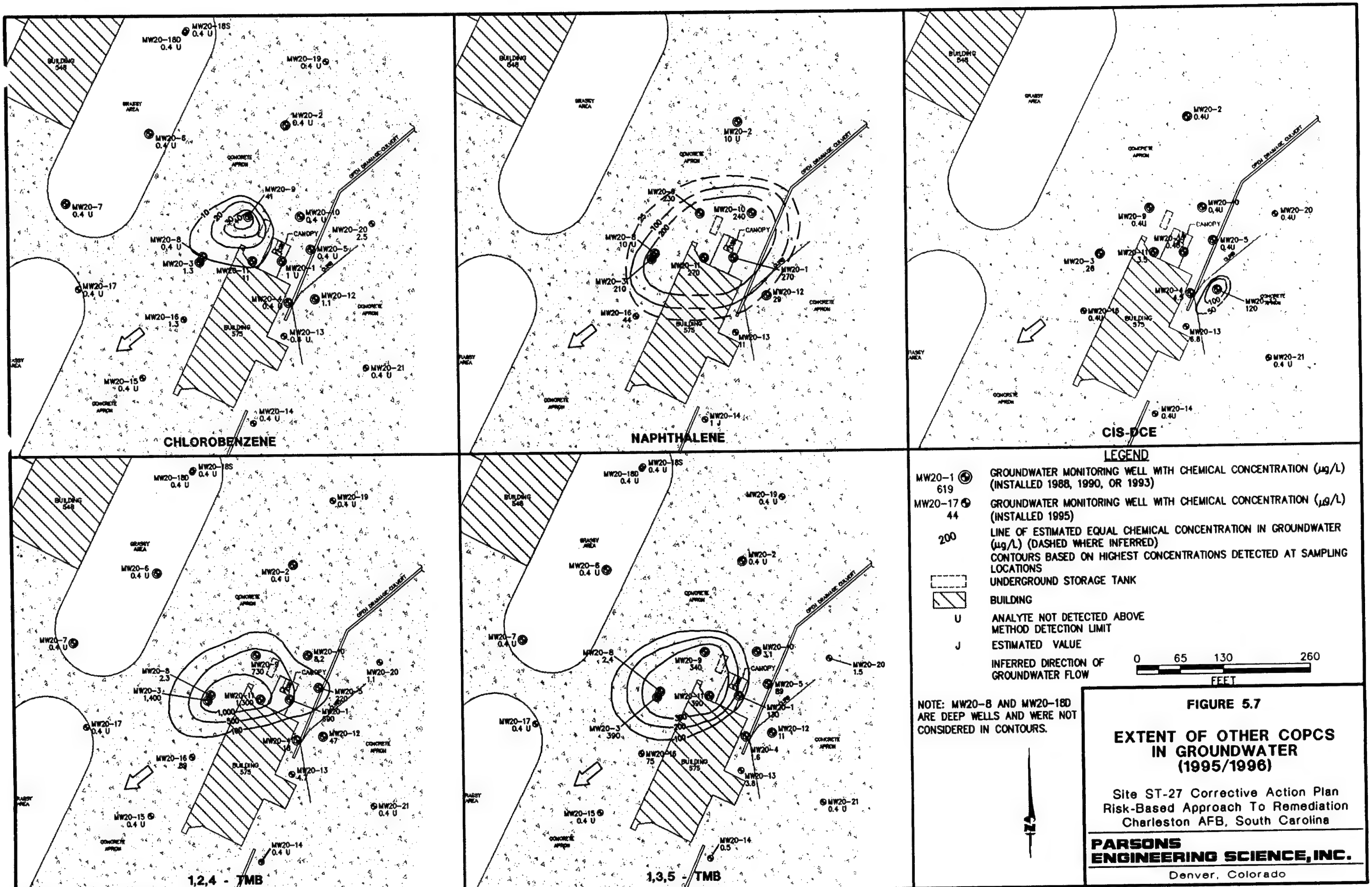

FIGURE 5.7

EXTENT OF OTHER COPCS IN GROUNDWATER (1995/1996)

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in a groundwater sample collected from MW20-12. Cis-DCE was detected in 5 of 21 wells sampled during the risk-based investigation (Figure 5.7).

5.5.3 Deep Dissolved Contamination

Benzene was detected in both deep wells at the site during the 1995 sampling event. Benzene was detected at concentrations of 7.7 μg/L at well MW20-8 and 5.9 μg/L at well MW20-18D. The presence of benzene contamination in well MW20-8 may indicate vertical extent of COPC impacts (i.e., measurable contamination beneath the source area to depths of between 23 and 32 feet). Detected concentrations of benzene in well MW20-18D may not be related to Site ST-27. No benzene was detected in the shallow well of this nested well (MW20-18S) or in the shallow well between MW20-18S and the source area (i.e., well MW20-6). Toluene was detected in both deep wells at the site during the 1995 sampling event, whereas ethylbenzene was detected only in deep well MW20-8 near the source area. Toluene was detected at concentrations of 2.4 μg/L at well MW20-8 and 1.7 μg/L at well MW20-18D. Ethylbenzene was detected at a concentration of 2.4 μg/L at well MW20-8. Naphthalene, chlorobenzene, and cis-DCE were not detected in either of the deep wells during any of the field investigations performed at the site. Both of the TMB isomers were detected at low concentrations in deep well MW20-8 near the source area, but not in well MW20-18D. Although the detected concentrations of COPCs in deep wells at Site ST-27 are well below even the most stringent Tier 1 RBSLs (see Section 4), the transport of these compounds to and within deeper portions of the Ladson Formation aquifer is considered in more detail in Section 6 of this CAP.

5.6 SUMMARY

Soil contamination at Site ST-27 is predominantly within saturated soils underlying the former location of the 3,000-gallon JP-4 jet fuel UST and the current location of the MOGAS and diesel USTs. Although concentrations of soil COPCs were measured in soil samples collected from the thin vadose zone at this site, the nature and extent of soil contamination suggests that the USTs leaked directly into soils below the water table. The contaminants identified as soil COPCs (BTEX, naphthalene, chlorobenzene, 1,3,5-TMB) all exceeded the Tier 1 RBSL for leaching; none exceeded a health-protective Tier 1 RBSL. Consequently, the long-term impacts of soil contamination on underlying groundwater at this site, accounting for site-specific conditions, are quantitatively considered in Section 6 of this CAP.

Several compounds (i.e., benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and cis-DCE) were identified as groundwater COPCs for Site ST-27. Dissolved contamination currently appears to impact an area of less than 2 acres within the immediate vicinity of the fueling dispenser island and canopy on the north side of Building 575. Although recent site data imply a southwesterly groundwater flow (and contaminant transport) direction, historical water table level measurements and compound-specific analytical data suggest that multi-directional groundwater flow (and contaminant transport) may occur at this site (see Figure 3.4). A comparison of compound-specific data at specific sampling locations over time shows that groundwater COPC concentrations generally are decreasing. The

effect of the chemical characteristics and site-specific characteristics of each of the groundwater COPCs on their fate and transport within both shallow and deeper flow zones of the Ladson Formation aquifer is examined in Section 6. Emphasis is placed on documenting the effects of natural physical, chemical, and biological processes on COPC mass, concentration, persistence, toxicity, and mobility.

SECTION 6

QUANTITATIVE TIER 2 CHEMICAL FATE ASSESSMENT

6.1 INTRODUCTION

The fate and transport of COPCs in environmental media at Site ST-27 must be considered when assessing the need for and feasibility of certain remedial approaches to mitigate potentially unacceptable risks to human or ecological receptors. The purpose of this section is to quantitatively estimate the effects of various site-specific attenuation processes. These processes include dispersion, diffusion, adsorption, and biodegradation. Particular emphasis is given to documenting verifiable COPC biodegradation in both soils and groundwater (SCDHEC, 1995). This section summarizes and interprets specific site characterization data relevant to documenting the effectiveness of natural chemical, physical, and biological processes that are minimizing COPC migration and reducing COPC concentration, mass, and toxicity over time. This quantitative fate assessment will be used to develop Tier 2 SSTLs (Section 7) and to determine whether natural attenuation (intrinsic remediation) may be an integral part of a cost-effective remedial approach for this site (Section 9).

As discussed in Section 4, none of the compounds detected in soil at Site ST-27 exceeded their respective health-protective RBSLs. However, each of the BTEX compounds, naphthalene, chlorobenzene, and 1,3,5-TMB were detected at concentrations above the Tier 1 soil leaching RBSLs designed to be protective of underlying groundwater quality. Each of the BTEX compounds also was measured in soil gas samples at concentrations well above their respective health-based RBSLs (Table 4.8). Several site-related compounds were detected in groundwater during recent sampling events at concentrations above health-protective Tier 1 RBSLs. Benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and *cis*-1,2-DCE were measured in groundwater during the 1995/1996 sampling events at concentrations above the most restrictive groundwater RBSL (Table 4.8). The short- and long-term fate and transport of these COPCs within and between affected environmental media at Site ST-27 is discussed in the following sections.

6.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of COPCs in environmental media is critical to evaluating and predicting contaminant distribution patterns. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. The following sections present a brief overview of the major chemical and physical characteristics that define the fate of COPCs in soil and groundwater at Site ST-27. These characteristics ultimately determine if the mass of contaminants in the environment can be eliminated or rendered immobile by natural processes. The

positive effects of these natural processes on reducing the actual mass of COPCs and/or minimizing leaching or the extent of migration in groundwater is termed intrinsic remediation.

6.2.1 Nondestructive Chemical Attenuation Processes

Nondestructive attenuation processes can be described as those physical and chemical processes that may prohibit significant contaminant migration but may not result in a permanent reduction in contaminant mass. Examples of nondestructive attenuation processes include volatilization, sorption, advection, and hydrodynamic dispersion. These processes must be evaluated when determining whether some type of remediation is warranted because chemical contamination poses or has the potential to pose a risk to human or ecological receptors. If contamination cannot reach a potential receptor, the contamination poses no risk.

6.2.1.1 Solubility

The water solubility of a chemical species defines how that particular chemical could partition (leach) from a contaminant source (e.g., LNAPL, contaminated soils) and dissolve into and migrate with groundwater. In general, lighter hydrocarbon chains tend to be more water soluble than heavier hydrocarbon chains. For example, the water solubilities of the soil COPCs are as follows: benzene, above 1,700 mg/L; toluene, above 500 mg/L; ethylbenzene, about 160 mg/L; xylenes, between 145 and 175 mg/L; chlorobenzene, about 500 mg/L; and naphthalene, about 30 mg/L (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Verschueren, 1983; Isnard and Lambert, 1988; Howard, 1990; Montgomery and Welkom, 1990). In comparison to the other soil COPCs, 1,3,5-TMB is relatively insoluble. Consequently, even though the lighter hydrocarbons such as the BTEX compounds and chlorobenzene may comprise a low mass fraction of the initial source of contamination (e.g., about 4 percent of JP-4 jet fuel), these compounds preferentially leach from contaminated soil or dissolve from LNAPL into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992).

As the Tier 1 RBSL evaluation suggested, dissolution of soluble contaminants from residual soil contamination and LNAPL is likely to be a significant source of continuing groundwater contamination at Site ST-27. All of the soil COPCs were identified based on exceedances of Tier 1 RBSLs for soil that are protective of underlying groundwater quality (i.e., soil leaching RBSLs). In addition, LNAPL thicknesses (up to 0.20 foot) or visible oily sheens have been measured in three permanent groundwater monitoring wells installed adjacent to and downgradient from the former leaking USTs at Site ST-27 since 1988 (i.e., wells MW20-1, MW20-3, and MW20-5). Chemical analytical results for the LNAPL (Table 5.1) suggest that a significant mass of soluble compounds such as the BTEX compounds still persists in the LNAPL. This means that LNAPL could represent a significant source of chemical contamination to underlying groundwater until such time as the source is naturally "weathered" (i.e., the more soluble compounds have been removed due to leaching and degradation processes) or remediated to the extent possible. The anticipated effects of dissolution of soluble contaminants from contaminated soils and LNAPL on groundwater quality are quantitatively evaluated in Sections 6.6.2 and 6.6.3, respectively.

6.2.1.2 Sorptive Properties

Another chemical characteristic that can govern how a compound may migrate (or become attenuated or occluded) within in soil and groundwater is its sorptive properties. Organic contaminants like the soil COPCs sorb to that portion of the soil matrix that is composed of organic carbon and fine clay particles. If a contaminant can be strongly sorbed to organic carbon and/or clay particles in either unsaturated or saturated soils, the compound will be less mobile and less likely to be transported great distances from the source area. Benzene does not sorb readily to soil and is considered the most mobile of the BTEX compounds (Abdul *et al.*, 1987). In comparison, naphthalene and 1,3,5-TMB sorb much more strongly to the soil matrix, and migration is limited in both soil and groundwater (Verschueren, 1983; Wiedemeier *et al.*, 1995).

The TOC content of both unsaturated and saturated soils was measured as part of the 1995 sampling event at Site ST-27. The TOC content measured in saturated soil samples collected in areas beyond detected contamination ranged from 0.06 to 0.13 percent (Appendix A). The surficial aquifer at Site ST-27 is composed of an upper silty sand unit, which is about 3 to 5 feet thick, and a lower clayey sand unit, which is about 4 to 7.5 feet thick. The water table of the surficial aquifer tends to occur in the clayey sand unit. The levels of TOC measured at some sampling locations at Site ST-27 indicate that organic contaminants could be retarded from leaching from soils and/or migrating in groundwater. The effect of sorption on contaminant leaching and velocity in groundwater is described in subsequent sections.

6.2.1.3 Volatility

The volatility of each of the COPCs also can affect how they behave in the environment. All of the BTEX compounds are volatile, with vapor pressures ranging from a high of about 96 millimeters of mercury (mm Hg) for benzene to a low of 10 mm Hg for xylenes (Montgomery and Welkom, 1990). The potential pathway involving volatilization from subsurface environmental media was not directly investigated as a mass transport mechanism at Site ST-27. The site is covered by up to 14 inches of concrete, which eliminates effective mass transfer via volatilization into the outdoor atmosphere. It is conceivable that elevated concentrations of gaseous vapors could accumulate underneath Building 575 and slowly diffuse into the indoor atmosphere through utility pathways or cracks in the building's foundation. As discussed in Section 5.4, all of the BTEX compounds were measured in soil gas samples (collected from at least 3 feet bgs) at concentrations above their respective TWA PELs. However, the concentration of a particular volatile compound at a potential exposure-point (e.g., above an excavation trench or inside Building 575) depends on the fate and transport of these compounds within and between affected environmental media over time. The potential for VOCs to diffuse from potential subsurface sources and migrate into the outdoor atmosphere under highly disruptive conditions (i.e., excavation activities that expose soils to the atmosphere) and indoor air at Building 575 is quantitatively evaluated in Section 6.6.1. These results are used to determine whether existing concentrations of contaminants in subsurface sources may pose an unacceptable health risk via the inhalation pathway.

6.2.1.4 Advection and Hydrodynamic Dispersion

Advective transport is the transport of contaminants by the bulk movement of groundwater. Hydrodynamic dispersion, which includes mechanical dispersion and diffusion, is another important process causing dilution of contaminants dissolved in groundwater. After contaminants dissolve into underlying groundwater, they migrate in the direction of groundwater flow at a rate that is retarded as a result of sorption to organic carbon found in aquifer matrix. Subsurface features that control the direction and rate of groundwater flow also control the direction and rate of contaminant migration. Whereas advection is controlled by macroscopic movement of groundwater, hydrodynamic dispersion is typically governed by molecular diffusion and/or tortuosity of groundwater flow through pore spaces. Hydrodynamic dispersive transport of contaminants tends to cause contaminant plumes to spread radially relative to the primary direction of groundwater flow. Hydrodynamic dispersive migration of contamination typically can broaden a contaminant plume, both in the transverse and longitudinal directions. Advective transport processes tend to have a more pronounced effect on contaminant migration than hydrodynamic dispersive transport processes. For this reason, longitudinal elongation of contaminant plumes in the downgradient direction is typically more pronounced than transverse broadening of contaminant plumes.

Advection and hydrodynamic dispersion of dissolved contaminants in groundwater underlying Site ST-27 will tend to reduce measurable concentrations over time but will not bring about a reduction in overall contaminant mass. Available water level data indicate that the groundwater table at this site can fluctuate from 1 to 3 feet on a seasonal basis, and that groundwater flow apparently has changed direction on several occasions (Section 3.4). The most consistent flow direction observed within the vicinity of Site ST-27 has been toward the southwest. This general direction of flow may be influenced by a slight mounding of groundwater immediately northeast of the location of the former USTs. Storm water percolating through cracks and/or joints in the culvert (shown in Figure 1.3) that runs through Site ST-27 may be of sufficient volume to cause a slight mounding of the low gradient groundwater, which causes groundwater to migrate generally toward the southwest. The absence of a significant flow gradient at this site, and the potential for multi-directional groundwater flow direction, are expected to have a significant impact on how chemicals are attenuated within saturated media at Site ST-27. These mass transport processes may in fact be acting to contain dissolved contamination near the source area by prohibiting significant migration in any one direction. The long-term fate and transport of dissolved contaminants--accounting for the influence of these hydrogeologic characteristics--is quantitatively investigated in Section 6.6.4. This information is used to establish point-of-action (POA) sampling locations and Tier 2 SSTLs for groundwater that will prevent increases in plume size or concentration and protect potential onsite receptors, should an exposure pathway involving groundwater be completed in the future (see Section 7).

6.2.2 Destructive Chemical Attenuation Processes

In comparison to nondestructive chemical attenuation processes, destructive chemical attenuation processes result in the permanent removal of contaminant mass from the environment and may reduce the length of time required to attain Tier 2 SSTLs (and eventually Tier 1 RBSLs). Documenting and distinguishing the effects of destructive

attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical to evaluating the potential for intrinsic remediation to bring about a reduction in contaminant mass over time. The effectiveness of destructive attenuation processes at reducing contaminant mass at a site depends on how amenable the chemical is to biodegradation and whether the site is characterized by physical, chemical, and biological conditions favorable to such processes.

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of different types of fuels (e.g., JP-4 jet fuel and MOGAS) under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, and 1988; Gibson, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989, and 1990; Leahy and Colwell, 1990; Parker *et al.*, 1990; Stieber *et al.*, 1990, 1994; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991a; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soils and groundwater with a history of exposure to fuel hydrocarbon compounds, such as Site ST-27, generally contain microbial populations capable of facilitating biodegradation reactions (Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994; Seech *et al.*, 1994; Simpkin and Giesbrecht, 1994). The chemical basis for the biodegradation of each of the COPCs is described in more detail in Section 6.4, where geochemical data relevant to documenting biodegradation at the field scale at Site ST-27 are presented.

6.3 EVIDENCE OF CONTAMINANT BIODEGRADATION OVER TIME AND DISTANCE

The first step in determining whether site data indicate that COPCs are biodegrading in soils and groundwater at Site ST-27 was to compare analytical data on the nature and extent of site contamination collected during previous investigations to analytical data on the nature and extent of site contamination collected from July 1995 through January 1996 as part of the risk-based investigation. The purpose of this comparison was to assess the evidence of field-scale contaminant mass loss. Changes in the nature and extent of contamination at a site over time that cannot be explained by physical processes (e.g., leaching from soils, mass transport in groundwater) may be the first indication that contaminants are biodegrading at the site.

6.3.1 Evidence of COPC Leaching from Soils

Limited compound-specific soil data were available prior to the 1995/1996 sampling events. None of the soil COPCs were detected in soil samples collected during the installation of MW20-9, MW20-10, MW20-11, and MW20-12 in 1993. Ethylbenzene, toluene, and xylenes were the only soil COPCs detected in August 1990. Each of these compounds was measured at concentrations above the Tier 1 soil leaching RBSLs that protect underlying groundwater quality. In fact, the only reported detected

concentrations of these compounds measured in August 1990 (Versar, Inc., 1992) were very similar to the maximum concentrations detected in 1995 during the risk-based soil sampling event. Ethylbenzene was detected at a concentration of 150 mg/kg in soils about 4 to 6 feet bgs at MW20-8 in 1990; in 1995, the maximum concentration of ethylbenzene of 150 mg/kg was measured in a soil sample collected at a sampling depth of 4 to 6 feet bgs at MP-4, which is about 90 feet upgradient from MW20-8. Toluene was detected at 160 mg/kg at MW20-8 in 1990; the maximum concentration of toluene measured in soil in 1995 was 320 mg/kg (MP-4). Xylenes were detected in the soil sample collected at 4 to 6 feet bgs at MW20-8 in 1990 at a concentration of 630 mg/kg. The maximum concentration of xylenes of 620 mg/kg detected in 1995 also was measured at sampling location MP-4. These analytical data seem to suggest that concentrations of some of the soil COPCs have not appreciably changed over the past 5 years, or that additional fuel leak(s) at this site may have masked the natural reduction of COPC mass.

The 14-inch-thick reinforced concrete that covers the source area at Site ST-27 is likely preventing significant percolation of precipitation through unsaturated soils. Consequently, the only significant contaminant mass transport mechanism that may mobilize sorbed contaminants in subsurface soils is seasonal changes in groundwater table elevation. The groundwater table fluctuates about 1 to 3 feet each year at this site (Section 3). Fuel hydrocarbon compounds, which were released directly into saturated soils and groundwater, may become occluded within soils as the groundwater table seasonally recedes. Then, as the groundwater table rises, these soils are again saturated, and occluded contaminants may desorb from soils and dissolve into surrounding groundwater. The seasonal nature of this mass transport mechanism will influence how much contaminant mass can be released annually into groundwater; however, because the soils will be fully saturated at times, the desorption process may actually be more effective than if this process were driven by precipitation leaching. The effectiveness of operative leaching processes in removing sorbed soil COPCs and dissolving them into underlying groundwater is quantitatively evaluated using site-specific analytical data and time-dependent equilibrium partitioning relationships in Section 6.6.2.

6.3.2 Observed Contaminant Loss from Groundwater

Analytical data from several permanent groundwater monitoring wells that were sampled and analyzed for several of the groundwater COPCs during different sampling events were compared to assess whether dissolved contaminant concentrations appeared to be decreasing over time. Table 5.2 presents the analytical results for some of the groundwater COPCs that were analyzed for during at least two sampling events. In general, as discussed in Section 5.6.2, dissolved benzene, toluene, ethylbenzene, and naphthalene concentrations have been decreasing at specific groundwater sampling locations over time. In addition to decreases at specific sampling locations, average concentrations by individual sampling event can be used to assess contaminant mass loss trends over time. By comparing the average concentration based on analytical results from several specific wells near the source area for different sampling events, it may be possible to determine whether dissolved contamination appears to be generally decreasing, increasing, or remaining stable over time. This type of comparison is only valid if the plume size remains relatively stable over time (i.e., reductions in the site average concentration are not due to physical dispersion of the plume). The data

presented in Figure 5.5 imply that the dissolved plume did not significantly changed in areal extent from 1988 to 1995. This means that reductions in site average groundwater COPC concentrations in the source area over time may be a good first indicator that contaminant mass loss is occurring.

Based on the historical analytical data collected at the same sampling locations over time (i.e., analytical data collected in 1988, 1990, and 1995 from wells MW20-1, MW20-3, MW20-4, and MW20-5, and analytical data collected in 1993 and 1995 from wells MW20-9, MW20-10, MW20-11, and MW20-12; presented in Table 5.1 and Figure 5.5), the average concentration of dissolved benzene near and within the source area was reduced by 34 percent from 1988 to 1990, and by an additional 45 percent from 1990 to 1995. Of the 45-percent reduction observed between the 1990 sampling event and the 1995 sampling event, available analytical data indicate that the average site dissolved benzene concentration was reduced by about 13 percent between the 1993 and the 1995 sampling events. Similar concentration reduction trends were observed for both toluene and ethylbenzene. The average concentrations of dissolved toluene and ethylbenzene near and within the source area were reduced by 34 percent and 8 percent, respectively, from 1988 to 1990, and by an additional 64 percent and 23 percent, respectively, from 1990 to 1995. Of the compound-specific concentration reductions observed between the 1990 sampling event and the 1995 sampling event, available analytical data indicate that the average site dissolved concentrations of both toluene and ethylbenzene were reduced by about 19 percent between the 1993 and the 1995 sampling events.

Naphthalene is the only other groundwater COPC for which historical groundwater analytical data are available. In comparison to benzene, toluene, and ethylbenzene, the site average of naphthalene has remained relatively stable or decreased only slightly (6 percent) over the last few sampling events. As is discussed in more detail in later sections, these data are not unexpected because naphthalene may be less amenable (but still susceptible) to destructive attenuation processes than the lighter fuel hydrocarbon compounds.

6.3.3 Discussion of Field-Scale Contaminant Mass Losses

There is limited evidence for natural attenuation of contaminants in soil at Site ST-27. Comparison of 1990 maximum soil concentrations to 1995 maximum soil concentrations implies that contaminants may be effectively occluded within site soils. It is possible that LNAPL at the site may be acting as a contaminant source for soils over time. As the groundwater table rises seasonally, contaminants partition from the LNAPL and "smear" the source area soils. An oily sheen was observed at MW20-3, which is about 10 feet southwest of MW20-8, during the 1988 site investigation. No LNAPL thicknesses or oily sheens have been observed at this sampling location since the 1988 investigation. However, the oily sheen may initially have acted as a contaminant source to shallow soils in this general vicinity. Once the oily sheen dissipated, occluded contaminants slowly leached from soils and dissolved into underlying groundwater. In comparison, soils in the vicinity of the former USTs, particularly near MW20-1 and MW20-5, may still be impacted by LNAPL.

The first line of evidence for natural attenuation of contaminants in groundwater at Site ST-27 is decreasing dissolved concentrations of groundwater COPCs measured at the same groundwater sampling locations and across the site over time. Comparison of previous sampling data to the 1995 site data indicate that dissolved benzene, toluene, ethylbenzene, and naphthalene are being attenuated. Average benzene concentrations decreased by a total of about 63 percent from June 1988 to August 1995 (i.e., over a period of about 86 months). The average concentration of toluene decreased by a total of about 76 percent during the same 86 months; average ethylbenzene groundwater concentrations decreased by a total of approximately 28 percent over the same 86-month period. Only very small reductions in naphthalene have been observed at the field scale over time.

The second line of evidence of natural attenuation of dissolved groundwater COPCs is the lack of significant migration over time. Benzene is the most soluble of the fuel hydrocarbon groundwater COPCs, and has the lowest affinity for soils. This means that benzene is one of the most mobile fuel hydrocarbon compounds present in JP-4 jet fuel and MOGAS. Yet, comparison of the current extent of dissolved benzene found at Site ST-27 to the extent of the other groundwater COPCs shows that benzene has not migrated as far downgradient as some of the higher-molecular-weight, less-mobile compounds such as ethylbenzene, xylenes, naphthalene, and the TMB isomers (see Figures 5.6 and 5.7). The benzene plume is attenuated relative to the other, less mobile compounds. This attenuation cannot be the result of the effects of nondestructive attenuation processes alone, as similar or even stronger processes would affect the migration of the other COPCs in groundwater. Because benzene is the most bioavailable of the groundwater COPCs, it appears that its migration is being significantly reduced by biodegradation.

Field data on groundwater velocity and TOC content was combined with the chemical-specific octanol-carbon partitioning coefficients (K_{oc}) for each of the groundwater COPCs to estimate contaminant velocities and expected travel distances from June 1988 to August 1995 (Table 6.1). Shallow groundwater flow is generally toward the southwest with an average hydraulic gradient of 0.002 ft/ft (Figures 3.4 and 3.5). The average hydraulic conductivity in the shallow wells tested as part of the risk-based investigation (Appendix C) was determined to be 2.61 ft/day, although hydraulic conductivity values ranged from 0.144 ft/day at MW20-21 to 5.76 ft/day at MW20-9. Coupling these site-specific data with an assumed porosity of 0.3, the average groundwater linear velocity in the shallow portion of the Ladson Formation was estimated to be 0.0175 ft/day (i.e., 6.2 ft/yr).

Because of the low hydraulic gradient at this site, contaminant migration was expected to be limited during the 86-month observation period. These travel estimates indicate that the plume is hydraulically contained. Consequently, the reduction in average site groundwater COPC concentrations and the lack of forward migration of significant concentrations of groundwater COPCs indicate that dissolved contaminants are being effectively attenuated in saturated media. This field-scale evidence suggests that mass removal processes such as biodegradation are operating at the site. In fact, in the absence of contaminant mass removal processes, the dissolved contaminant plume could not decrease in concentration without increasing in size over time.

TABLE 6.1
EXPECTED CONTAMINANT TRAVEL DISTANCES DUE TO NONDESTRUCTIVE ATTENUATION PROCESSES
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Compound	Advective Groundwater Velocity (ft/day)	Partition Coefficient (L/kg)[a/]	Contaminant Velocity (ft/day)[b/]	Expected Travel Distance (6/88-8/95) (ft)[c/]
Benzene	1.75E-02	0.19	1.00E-02	26
Toluene	1.75E-02	0.67	4.76E-03	13
Ethylbenzene	1.75E-02	0.48	0.60E-02	16
Naphthalene	1.75E-02	6.44	0.66E-03	1.5
Chlorobenzene	1.75E-02	1.66	2.31E-03	6
1,2,4-TMB	1.75E-02	4.42	0.94E-03	2.5
1,3,5-TMB	1.75E-02	3.38	1.21E-03	3
cis-DCE	1.75E-02	0.32	7.67E-03	20

[a/] Partition coefficient based on fractional organic carbon content of = 0.005 and octonal-carbon partition coefficient (K_{oc}) values (Montgomery and Welkom, 1990; Wiedemeier *et al.*, 1995).

[b/] Calculated using relationship: velocity of groundwater/retardation coefficient. The retardation coefficient is defined as [1+((1-n)/n)*density soil*partition coefficient)], where n is the porosity of the medium.

[c/] Travel distance was calculated by multiplying the contaminant velocity by the number of days between the two sampling events.

6.3.4 Estimating Site-Specific Contaminant Biodegradation Rates

It is important to distinguish between the effects of nondestructive attenuation processes (i.e., advection, dispersion, and sorption) and the effects of destructive attenuation processes (i.e., biodegradation) on the mass of dissolved groundwater COPCs in the groundwater at Site ST-27. Comparison of analytical data from several sampling events suggest that at least some of the groundwater COPCs are being removed from saturated soils and groundwater by mechanisms other than dispersion, advection, and sorption. To quantify these effects, an exponential regression method can be used to derive degradation rates from concentration reduction data versus time (Buscheck and Alcantar, 1996). The reduction in COPC concentrations at specific sampling points and the reduction in site average COPC concentrations can be easily used to estimate a first-order attenuation rate, provided the plume size is relatively stable or decreasing. It is commonly assumed that biodegradation rates for fuel hydrocarbons in saturated media can be approximated by a first-order decay constant (Chapelle, 1993). The solution to the first-order decay is:

$$C_{(t)} = C_i e^{(-kt)}$$

Where:
$C_{(t)}$ = concentration at time t
C_i = initial concentration
k = decay rate (T^{-1})
t = time

Table 6.2 summarizes the calculated biodegradation rates for each of the groundwater COPCs, based on reductions in contaminant concentrations measured at specific sampling points over time and reductions in the average site contaminant concentrations over time. These degradation rates express the quantity of the contaminant mass being removed from the saturated media that cannot be explained by nondestructive attenuation processes such as dispersion and adsorption. The effects of both aerobic and anaerobic destructive attenuation processes are included in these site-specific biodegradation rate-constant estimates. The potential for additional hydrocarbons to leach from "smeared" soils and LNAPL into groundwater was not factored into the rate estimates. As a result, the estimated rates underestimate the effectiveness of biodegradation processes at the site.

Based on these estimated degradation rates, the average half-life of benzene in saturated soils and groundwater at Site ST-27 is about 5 years; the half-life of toluene is about 3.5 years; the half-life of ethylbenzene is about 15 years; and the half-life of naphthalene is about 24 years. Calculated site-specific degradation rates could be developed for only four of the groundwater COPCs. Only limited (or no) historical sampling data are available for the other COPCs (chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and *cis*-1,2-DCE). Without historical sampling data and/or a clear flow path (due to the potential for multi-directional flow at the site), it was not possible to estimate site-specific destructive attenuation rates for these compounds. The half-life of chlorobenzene is reported in the technical literature to be as short as 68 to 300 days (Howard *et al.*, 1991), which falls between the reported half-life ranges for benzene and ethylbenzene. However, given the site-specific degradation rates for the other

TABLE 6.2
COMPOUND-SPECIFIC BIODEGRADATION RATES
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Groundwater COPC	Change in Site Average Concentration[a/]	Change Range in Concentration at Specific Sampling Locations[b/]	Average Site-Specific Degradation Rate (day^{-1})[c/]	Range in Estimated Degradation Rates (day^{-1})[c/]	Literature-reported Biodegradation Rates (day^{-1})d/
Benzene	0.36	0.05 - 0.64	3.87E-04	1.14E-3 - 1.71E-4	9E-4 - 0.23
Toluene	0.24	0.015 -0.6	5.51E-04	1.61E-3 - 1.95E-4	2.5E-2 - 9.8E-2
Ethylbenzene	0.72	0.06 - 0.8	1.28E-04	1.07E-3 - 8.53E-5	3E-3 - 1E-1
Naphthalene	0.94	0.82 -1	7.79E-05	2.72E-4 - 0	2.4E-3 - 6.9E-1

[a/] Dimensionless change estimated as (1988 site average/1995 site average).

[b/] Dimensionless change estimated using measured reductions at specific sampling points (see Table 5.2).

[c/] Degradation rate estimated using first-order decay equation described in text; t = 2,615 days for all but naphthalene (where reductions were observed between the 1993 and 1995 sampling event, 730 days).

[d/] Based on degradation rates reported by Howard *et al*., (1990).

groundwater COPCs, the site-specific half-life of chlorobenzene in saturated soils and groundwater is anticipated to be on the order of 5 to 10 years (i.e., between the site-specific half-lives for benzene and ethylbenzene). The half-life of *cis*-1,2-DCE is reported in the technical literature to range from a few months to about 8 years (Howard *et al.*, 1991). This means that the site-specific half-life of *cis*-1,2-DCE in saturated soils and groundwater at Site ST-27 may be similar to that estimated for benzene (i.e., 5 years), but possibly as long as that estimated for naphthalene (i.e., 24 years). Additional sampling data are necessary to assess the susceptibility of this compound to destructive attenuation processes over time. Finally, the last two groundwater COPCs (i.e., 1,2,4-TMB and 1,3,5-TMB) have been reported to be relatively recalcitrant to destructive attenuation processes under anaerobic conditions (Cozzarelli *et al.*, 1990 and 1994). Based on analytical data collected at other sites as part of AFCEE-sponsored initiatives, these two TMB isomers may be expected to have half-lives on the order of about 1 year in a relatively aerobic system. Because the shallow groundwater at Site ST-27 is predominantly anaerobic (Section 6.4), these two groundwater COPCs may be very persistent in onsite saturated soils and groundwater. These compounds are anticipated to be effectively attenuated by nondestructive attenuation processes (Table 6.1).

6.4 EVIDENCE OF CONTAMINANT BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Available site data suggest that the BTEX compounds, naphthalene, and possibly the other groundwater COPCs are biodegrading in saturated soils and groundwater at Site ST-27. There were measurable decreases in the concentrations at select sampling locations and in the site average concentrations of each specific compound over the course of several sampling events. A simple exponential regression method (i.e., first-order decay) was used to estimate site-specific destructive degradation rates for benzene, toluene, ethylbenzene, and naphthalene. Information found in the technical literature on the degradation rates for the other groundwater COPCs was qualitatively extrapolated to Site ST-27 in the absence of historical monitoring data. On the basis of this evaluation, it can be inferred that the groundwater COPCs, particularly the fuel hydrocarbon compounds, are biodegrading at Site ST-27.

There is also another line of evidence that can be used to show that these contaminants are biodegrading in saturated soil and groundwater at Site ST-27. The fuel hydrocarbon groundwater COPCs (i.e., benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, and the TMB isomers) are typically utilized as electron donors in biologically mediated redox reactions under a wide range of geochemical conditions. While it is believed that *cis*-1,2-DCE cannot be utilized as an electron donor in biodegradation reactions, evidence suggests that under specific geochemical conditions, this chemical can serve as an electron acceptor in such reactions (Bouwer, 1994; McCarty and Semprini, 1994). Because all of the COPCs can be utilized in biologically mediated redox reactions, analytical data on potential electron acceptors can be used as geochemical indicators of COPC biodegradation (Salanitro, 1993; McCallister and Chiang, 1994; Wiedemeier *et al.*, 1995; Borden *et al.*, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of fuel hydrocarbon compounds within contaminated media is an indication that contaminants are biodegrading. Alternately, an increase in the metabolic byproducts

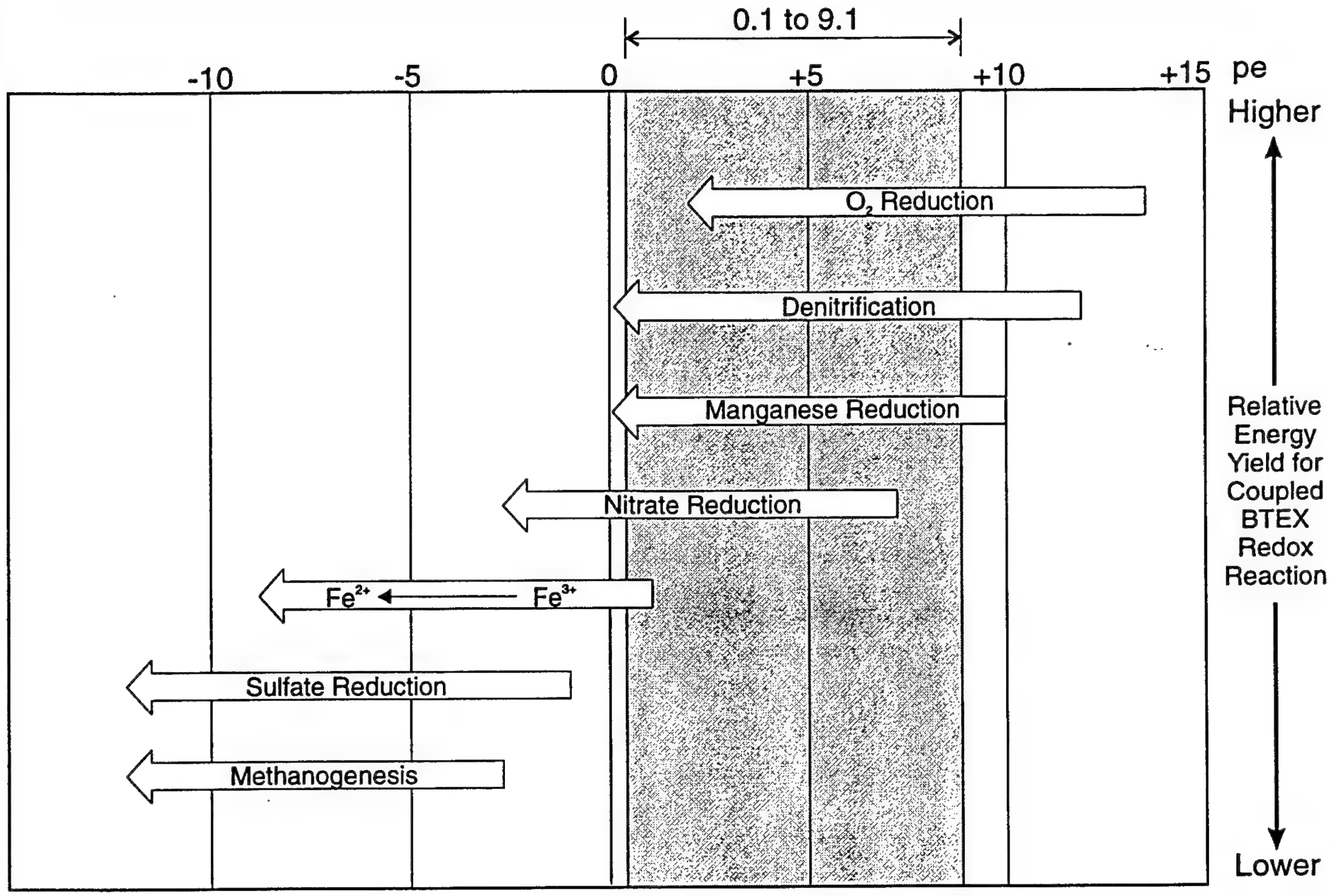
resulting from the reduction of electron acceptors can be used as an indicator of contaminant biodegradation. The availability of potential electron acceptors to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded over time at this site. Coupled with the biodegradation rates described earlier, this information can be used to predict how much and how quickly groundwater COPCs can be permanently removed from saturated soils and groundwater at Site ST-27 as a result of natural processes only.

6.4.1 Relevance of Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of all of the groundwater COPCs is the result of a series of redox reactions that maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of these organic compounds by transferring electrons from the electron donor (i.e., benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, TMB, native organic carbon) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving these available electron donors. Electron acceptors known to be present in saturated soil and groundwater at Site ST-27 are oxygen, nitrate, manganese, sulfate, ferric iron, and carbon dioxide. In addition, chlorinated hydrocarbons such as *cis*-1,2-DCE, which is present in the groundwater at the site as a result of upgradient activities, can serve as alternate electron acceptors under appropriate geochemical conditions (Bouwer, 1994).

Microorganisms facilitate fuel hydrocarbon biodegradation to produce energy for their use. The amount of energy that can be released when a reaction occurs or is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Bouwer, 1994; Chapelle, 1993; Godsey, 1994; Mueller *et al.*, 1994; Berg *et al.*, 1994). Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes (i.e., cell production and maintenance). Microorganisms will facilitate only those redox reactions that will yield energy. By coupling the oxidation of fuel hydrocarbon compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, carbon dioxide, and possibly *cis*-1,2-DCE), which yields energy, the overall reaction will yield energy. Detailed information on the redox reactions required to biodegrade each of the groundwater COPCs is included in Appendix E. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 6.1 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As Figure 6.1 shows, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, *cis*-1,2-DCE, and finally carbon



Notes

Range of pe measured at Site ST-27

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.

2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the pe of the system.

3. The pe of the system determines which electron acceptors are available for COPC oxidation.

4. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 6.1

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

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dioxide. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

The expected sequence of redox processes is also a function of the oxidizing potential (Eh) of the groundwater. The oxidizing potential measures the relative tendency of a solution or chemical reaction to accept or transfer electrons. The oxidizing potential of the groundwater can be measured in the field. This measurement can be used as a crude indicator of which redox reactions may be operating at a site. This field measurement can then be expressed as pe, which is the hypothetical measure of the electron activity associated with a specific Eh. High pe means that the solution or redox couple has a relatively high oxidizing potential.

Microorganisms can only facilitate the biodegradation (oxidation) of the fuel hydrocarbon compounds using redox couples that have a higher oxidizing potential than the contaminants. Appendix E includes tables that show that redox couples including nitrate, oxygen, ferric iron, sulfate, *cis*-1,2-DCE, and carbon dioxide all have higher oxidizing potentials than the redox couples including the fuel hydrocarbon COPCs. This is why these electron acceptors can be used to oxidize the fuel hydrocarbon compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 6.1, the reduction of oxygen and nitrate will reduce the oxidizing potential to levels at which ferric iron (Fe^{3+}) reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently low (negative) pe levels have been developed as a result of these redox reactions, sulfate reduction, *cis*-1,2-DCE anaerobic reductive dehalogenation, and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

The range of pe in the groundwater at Site ST-27, based on Eh measurements collected in the field, is 0.14 to 9.14 (Figure 6.1). These data imply that oxygen, nitrate, manganese, ferric iron, and *cis*-1,2-DCE may be used to biodegrade fuel hydrocarbon contaminants at these sites. Analytical data on oxidized and reduced species are presented in the next sections to verify which electron acceptors are actually being used to biodegrade the groundwater COPCs in saturated soil and groundwater at Site ST-27.

6.4.2 Dissolved Oxygen Concentrations

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of the fuel hydrocarbon compounds yields a significant amount of free energy to the system that the microorganisms could utilize.

DO concentrations were measured at groundwater sampling locations in August 1995 (and again in January 1996 at all locations). Figure 6.2 presents the 1995 analytical results for DO by sampling location. The isoconcentration contours show that there is a strong correlation between areas that are currently contaminated with fuel hydrocarbons or within the intended flow path of fuel hydrocarbon contamination and areas depleted of DO relative to measured background levels. DO concentrations measured within the source area and at the nearest downgradient well did not exceed 0.5 mg/L. In comparison, background DO concentrations at this site ranged between 1.5 and 4 mg/L, as indicated by results for MW20-2, upgradient from the source area, and for other monitoring points that were outside the area of fuel contamination (e.g., MW20-6 and MW20-17). This DO distribution indicates that oxygen functions as an electron acceptor during microbially mediated degradation of fuel hydrocarbons; however, anaerobic processes are expected to dominate in the core of the plume as a result of the depleted DO. The occurrence of anaerobic degradation within the core of the contaminant plume surrounded by a zone of aerobic degradation along the fringe of the plume is consistent with the measured Eh levels (redox potentials) at the site (Figure 6.1).

6.4.3 Dissolved Nitrate Concentrations

Because near-anaerobic conditions generally prevail in the site groundwater, nitrate can be used as an electron acceptor by indigenous facultative anaerobic microorganisms to mineralize fuel hydrocarbon compounds via either denitrification or nitrate reduction processes.

Nitrate was measured at groundwater sampling locations in August 1995. Figure 6.2 presents the analytical data for nitrate. Figure 6.2 shows that there is no significant depletion of nitrate near or downgradient from Site ST-27 relative to measured background concentrations. This implies that neither denitrification nor nitrate reduction is occurring at Site ST-27. Although the redox potential data collected at the site seemed to imply that nitrate could be involved in fuel hydrocarbon degradation reactions occurring at the site, the lack of significant background concentrations of nitrate has minimized the potential importance of this degradation reaction. The shallow groundwater simply does not contain sufficient concentrations of nitrate to support redox reactions.

6.4.4 Manganese Concentrations

Manganese also can be used as an electron acceptor to facilitate the oxidation of the fuel hydrocarbon groundwater COPCs under anaerobic and slightly reducing conditions. In fact, as Figure 6.1 shows, manganese reduction can be microbially facilitated in groundwater conditions similar to those required to support denitrification. The reduction of manganese during the oxidation of fuel hydrocarbon compounds yields essentially as much free energy to the system as aerobic respiration. Under anaerobic and slightly reducing groundwater conditions, manganese reduction is the second-most energetically favorable redox reaction that can be used to oxidize (degrade) fuel hydrocarbon compounds.

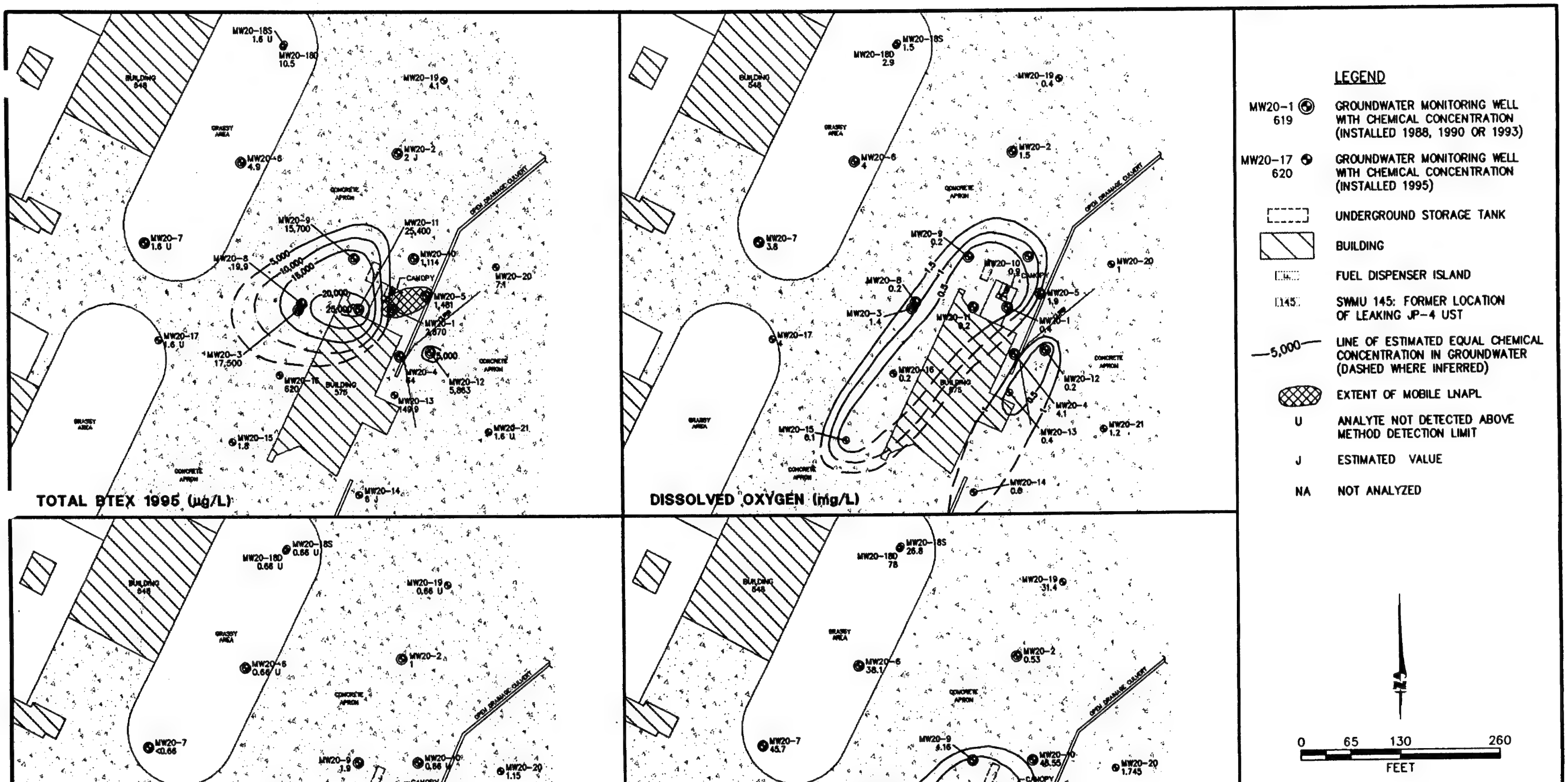

FIGURE 6.2

EXTENT OF OXIDIZED ELECTRON ACCEPTORS

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Reduced forms of manganese were measured at groundwater sampling locations in August 1995. Reduced forms of manganese would be produced locally if oxidized forms of manganese were being used to oxidize other compounds, such as fuel hydrocarbons. As Figure 6.3 shows, elevated concentrations of reduced manganese correspond well to areas where elevated concentrations of the fuel hydrocarbon groundwater COPCs were detected. The maximum concentration of reduced manganese of 19.7 mg/L was detected at MW20-1, the same sampling location where about 2,870 μg/L of total BTEX was measured in 1995. When compared to background concentrations of reduced manganese (which were below detection limits), the elevated concentrations measured in the source area strongly indicate that manganese is being used to oxidize fuel hydrocarbons in the anaerobic core of the dissolved plume. These analytical data are consistent with the pe levels measured in this region as well.

6.4.5 Ferrous Iron Concentrations

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). Elevated concentrations of ferrous iron (Fe^{2+}) often are found in anaerobic, fuel-contaminated groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as benzene. However, recent evidence suggests that the reduction of ferric iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires mediation by microorganisms with the appropriate enzymatic capabilities. The reduction of ferric iron results in the formation of ferrous iron.

To determine if ferric iron is being used as an electron acceptor for fuel biodegradation at Site ST-27, ferrous (reduced) iron concentrations were measured at groundwater sampling locations. Figure 6.3 presents the analytical results for ferrous iron in groundwater at this site. Areas characterized by elevated concentrations of dissolved fuel hydrocarbons correspond well with areas of elevated concentrations of ferrous iron relative to measured background concentrations. Ferrous iron was measured near or below the detection limit in background wells and most wells located outside the areas affected by fuel contamination. However, the concentrations of ferrous iron at sampling locations where elevated concentrations of groundwater COPCs were measured were as high as 35 mg/L.

The correlation between elevated dissolved hydrocarbon contamination and elevated ferrous iron concentrations suggests that the iron-reducing microorganisms are using ferric iron to oxidize the contaminants. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in contaminated groundwater underlying Site ST-27 are strong indicators of microbial activity. These geochemical data suggest that iron-reducing

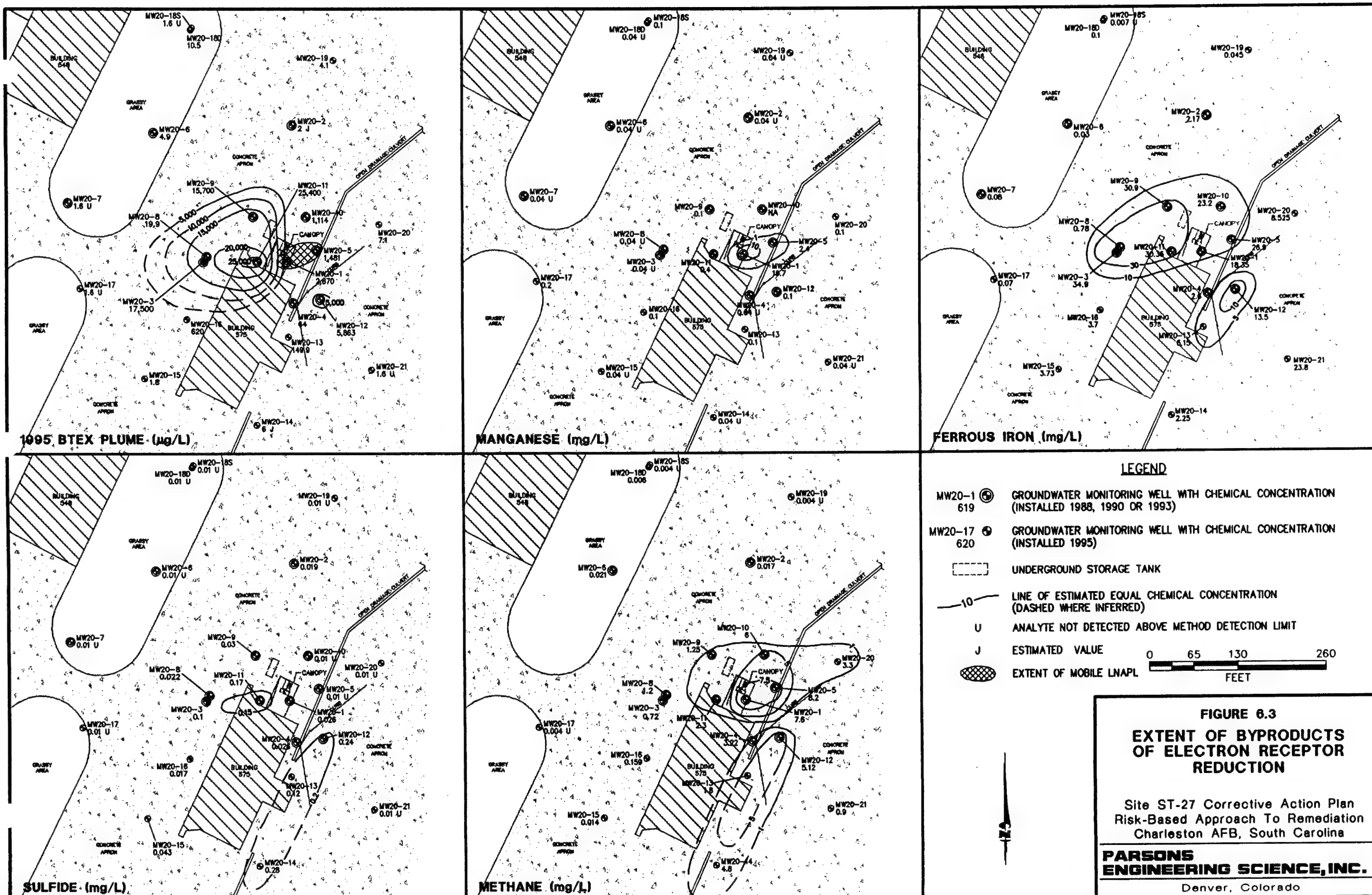

FIGURE 6.3

EXTENT OF BYPRODUCTS OF ELECTRON RECEPTOR REDUCTION

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microorganisms are present in the groundwater at the site, and that these microorganisms are using ferric iron to energize fuel hydrocarbon metabolism.

Measured pe levels at the site are slightly higher than the range of pe typically associated with ferric iron reduction (Figure 6.1). This is a common problem associated with measuring oxidizing potential using field instruments. Many authors have noted that field redox potential data alone cannot be used to reliably predict the electron acceptors that may be operating at a site (e.g., Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994). Integrating redox potential measurements with analytical data on reduced and oxidized chemical species allows a more thorough and reasonable interpretation of which electron acceptors are being used to biodegrade site contaminants.

6.4.6 Sulfate Concentrations

Sulfate also may be used as an electron acceptor during microbial degradation of the fuel hydrocarbon COPCs under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate can be reduced to sulfide during the oxidation of the fuel hydrocarbon compounds. The presence of decreased concentrations of sulfate (and possibly increased concentrations of sulfide) in the source area relative to background concentrations indicates that sulfate may be participating in redox reactions at the site. To investigate the potential for sulfate reduction at Site ST-27, total sulfate and sulfide concentrations were measured at groundwater sampling locations.

Figures 6.2 and 6.3 show the analytical results for sulfate and sulfide, respectively, in groundwater at Site ST-27. In general, areas characterized by elevated concentrations of dissolved COPCs are depleted in sulfate concentrations relative to measured background concentrations. Background concentrations of sulfate at the site ranged from 0.53 mg/L at MW20-2 to 58.6 mg/L at MW20-17. Sulfate concentrations measured at sampling locations with elevated fuel hydrocarbon concentrations ranged from 4.16 mg/L near the core of the dissolved plume to 5.1 mg/L at MW20-3 near the leading edge of the dissolved plume. This general depletion of sulfate within the contaminated area suggests that this compound is also acting as an electron acceptor. Figure 6.3 shows that elevated concentrations of sulfide, which is produced when sulfate is reduced during fuel hydrocarbon oxidation, are roughly coincident with elevated dissolved COPC contamination. Sulfide was not detected in wells outside the area of detectable levels of dissolved fuel hydrocarbon contamination. The depletion of sulfate and some detection of sulfide within the contaminated area indicates that sulfate is acting as an electron acceptor at this site.

The measured redox potentials of the groundwater at this site are higher than would be expected for the sulfate-reducing conditions implied by the observed sulfate and sulfide distributions. Sulfate reduction can be mediated only in reducing conditions (low pe). Measured redox potentials at Site ST-27 were not sufficiently low enough to suggest that sulfate reduction could occur at the site (Figure 6.1). It is likely that the platinum electrode probes of the field instrument were not sensitive to the sulfate/sulfide redox couple. As discussed in Section 6.4.5, this is a common problem associated with measuring oxidizing potential using field instruments.

6.4.7 Dissolved Methane Concentrations

On the basis of free energy yield and the oxidizing potential of the site groundwater, the carbon dioxide-methane (CO_2-CH_4) redox couple also could be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing levels, other highly oxidizing chemical species such as oxygen, nitrate, and sulfate must be reduced. This redox reaction is called methanogenesis or methane fermentation. Methanogenesis yields the least free energy to the system in comparison to other chemical species (Figure 6.1 and Appendix E). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

Dissolved methane was measured at several groundwater monitoring wells as part of the August 1995 sampling event. Figure 6.3 presents the analytical data for methane by sampling location. Methane was detected at several sampling locations at substantially elevated concentrations (relative to background levels), ranging from 2.3 mg/L to 18 mg/L. The presence of methane in groundwater at Site ST-27 indicates that biodegradation processes have occurred via methanogenesis. The production of significant concentrations of methane is likely attributable to the highly anaerobic nature of the groundwater in the core of the dissolved plume, and the slow contaminant transport velocities. Methane has been produced and is accumulating in groundwater underlying and immediately downgradient from the suspected source.

6.5 THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if fuel hydrocarbon COPCs are biodegrading in saturated soils and groundwater at Site ST-27. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of fuel hydrocarbons and the reduction of electron acceptors to generate free energy for cell maintenance and production. The question of how much contaminant mass can be biodegraded must be addressed to assess the full potential for long-term intrinsic remediation to minimize plume size and mass over time, and to eventually reduce COPC concentrations to at least Tier 2 SSTLs (Section 7).

Mass balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the expressed assimilative capacity of the groundwater. Once the redox reactions operating at the site have been defined, it is possible to estimate how much contaminant mass can be assimilated or oxidized by available electron acceptors. This analysis, when coupled with the biodegradation rate information discussed earlier (Table 6.2), provides the basis for determining the potential for continued COPC mass reduction in saturated soils and groundwater at the site.

Appendix E presents the coupled redox reactions that represent the biodegradation of each of the groundwater COPCs. These tables also present the stoichiometric mass ratio of electron acceptors needed to oxidize each of the groundwater COPCs. These stoichiometric mass ratios can be used to estimate the assimilative capacity of the

groundwater at Site ST-27. This is accomplished by first determining the initial (background) mass of each electron acceptor available in the groundwater. Data on these chemical species were collected at sampling locations upgradient from and outside of the dissolved plume. As groundwater slowly migrates into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site contamination. The change in the electron acceptor mass from upgradient sampling locations to sampling locations within the source area is divided by the mass of electron acceptors required to mineralize each of the fuel hydrocarbon COPCs to estimate the expressed intrinsic capacity of the groundwater to biodegrade these compounds.

Average estimates of the background concentrations of all of the electron acceptors that are being used at the site to biodegrade fuel hydrocarbon compounds are listed in Table 6.3. These concentrations are used to calculate the available or expressed assimilative capacity of each electron acceptor for benzene, toluene, and ethylbenzene (BTE) and for the combined COPCs (BTEX plus naphthalene, chlorobenzene, and the TMB isomers) based on the mass stoichiometric relationships presented in detail in Appendix E. Table 6.3 also presents the source area concentrations of reduced manganese, ferrous iron, and methane. These concentrations are used to "back-calculate" the expressed assimilative capacity that is attributable to manganese reduction, ferric iron reduction, methanogenesis. Although *cis*-1,2-DCE also could be used to biodegrade fuel hydrocarbons, there are insufficient data to quantify this process. Consequently, this compound was not used to estimate expressed assimilative capacity. On the basis of these calculations, the saturated soils and groundwater at Site ST-27 has the intrinsic capacity to eventually oxidize a total BTE concentration of 18,600 μg/L or a total COPC concentration of approximately 16,900 μg/L.

This estimate essentially represents an upper-bound estimate of the intrinsic mass reduction capability of the groundwater at Site ST-27. The estimate identifies how much contaminant mass can be theoretically oxidized as one pore volume travels through the plume core. So, although the capacity is expressed in μg/L, the capacity is actually an estimate of the micrograms of contaminant mass that can be degraded in the volume of groundwater traveling through the core plume. A closed system containing 2 liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly "x" mg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these 2 liters of water are kept separate, the biodegradation of fuel hydrocarbons will not occur. If these 2 liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment becomes acutely toxic to the fuel-degrading microorganisms. Assuming a nonlethal environment, if less than "x" mg of fuel hydrocarbons are in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "x" mg of fuel hydrocarbons were in the second liter of water, only "x" mg of fuel hydrocarbons would ultimately degrade.

This example shows, that in a closed system, the measured expressed assimilative capacity eventually should be equivalent to the loss in contaminant mass; however, the groundwater beneath a site is an open system. Electron acceptors can continually enter the system from upgradient flow. Furthermore, contaminant mass can be added to the

TABLE 6.3
ESTIMATE OF EXPRESSED ASSIMILATIVE CAPACITY OF SATURATED SOIL AND GROUNDWATER
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
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Electron Acceptor	Background Concentration (μg/L)	Utilized Electron Acceptor Mass (μg/L)	BTE Assimilative Capacity[a] (μg/L)	Combined COPC Assimilative Capacity[a] (μg/L)
Oxygen	1500	1300	416	446.1
Manganese[b]	19700	19700	1809	1351.5
Ferric iron[b]	30000	27800	1276	797.7
Sulfate	5100	26300	5523	6018.3
Methane[b]	7540	7483	9578	8314.4
		Total	18603	16928
		1988 Maximum	31230	>31230
		1995 Maximum	19300	21941

[a] Calculated based on the ratio of the total mass of electron acceptor required to oxidize a given mass of total benzene, toluene, and ethylbenzene (BTE) or total COPC mass, assuming no other source of oxidizing demand (Appendix E).

[b] This represents the reduced form of the electron acceptor. Assimilative capacity is expressed only as an estimate.

system through dissolution or leaching from LNAPL or contaminated soils. This means that the assimilative capacity is not fixed as it would be in a closed system, and therefore should not be quantitatively compared to concentrations of dissolved contaminatns in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. The fate of COPCs in groundwater is dependent on the relationship between the kinetics of biodegradation and the solute transport velocities (Chapelle, 1994).

6.6 PREDICTING CONTAMINANT TRANSPORT AND FATE

Understanding the effects of natural physical, chemical, and biological processes on chemicals is an important step in determining potential long-term risks associated with chemical migration in the environment. The behavior of COPCs under the influence of these processes must be quantified to predict the extent that soil COPCs could leach from mobile or residual LNAPL and dissolve into underlying groundwater; to assess the expected persistence, mass, concentration, and toxicity of dissolved COPCs over time at the site; and to estimate potential receptor exposure-point concentrations. If destructive and nondestructive attenuation processes can minimize or eliminate the concentration of COPCs to which a receptor could be exposed, engineered remedial action may not be warranted because no reasonable completed exposure pathway exists or completion of exposure pathways involving groundwater would not result in significant risks. The focus of this final subsection is to predict how COPCs will be transported and transformed over time in LNAPL, soil, and groundwater based on site data and simple mathematical solute transport calculations assuming no engineered remedial action is undertaken at Site ST-27.

6.6.1 Volatilization from Subsurface Sources

Maximum detected soil gas concentrations were conservatively compared to air RBSLs to define ambient atmosphere COPCs in Section 4.3.2. However, as discussed previously, this comparison was expected to be overly conservative because soil gas measurements (collected beneath the 14-inch concrete apron) do not reflect the exposure-point concentrations in outdoor ambient air or within Building 575. To determine whether subsurface sources (i.e., mobile LNAPL, contaminated soils, and dissolved contamination) could cause exposure-point concentrations in either outdoor or indoor air that may pose an unacceptable risk to potential onsite receptors via the inhalation exposure route, several different kinds of chemical flux and atmospheric transport equations were coupled to simulate the concentrations of volatile COPCs present in outdoor ambient air under normal atmospheric conditions and the concentrations of volatile COPCs accumulating within onsite buildings. Most of the equations are based on the predictive contaminant migration equations presented by ASTM (1994) in the *Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. However, the equations for estimating flux into and resultant concentration within an enclosed space as presented in the ASTM (1994) guide are incorrect. Consequently, two simple, alternate models [i.e., the Farmer Model (USEPA, 1992b) and the indoor air dispersion model (Michelson *et al.*, 1993)] were used instead.

Three different types of COPC migration equations were used to predict the transport of VOCs from subsurface sources through unsaturated soils and manmade structures (e.g., building foundations), and within ambient air. Equilibrium partitioning equations were used to estimate the mass of volatile COPCs that theoretically could partition from dissolved contamination, mobile LNAPL, and contaminated soil. The theoretical source term based on equilibrium partitioning equations is expected to overestimate the COPC mass present in the vapor phase at Site ST-27. These equations assume linear partitioning and a constant and nondiminishing source (e.g., no reduction in source term as a result of volatilization, biodegradation, or other attenuation mechanisms). In addition to these conservative assumptions, the COPC mass contributed from dissolved contamination, mobile LNAPL, and contaminated soil was cumulatively accounted for in the resultant theoretical source term. For comparison, the maximum measured soil gas concentrations also were used to represent the observed subsurface source term. Thus, a range of possible air quality impacts were quantified by using both a theoretical (upper bound) and observed source term.

Flux equations were then used to estimate that mass of volatile COPCs that migrated to the target mixing area (i.e., outdoor ambient atmosphere and indoor building space). Simple "box" mixing equations were used to translate flux measurements into predicted exposure-point concentrations for air within the outdoor and indoor breathing zones. Outdoor air quality impacts were conservatively estimated assuming that volatile COPCs diffuse/convect through native soils only (i.e., assumes that the concrete apron is not present), and that only minimal atmospheric dispersion above the flux area is possible (i.e., virtual upwind point-source dispersion assumption). Indoor air quality impacts were conservatively estimated by allowing COPCs to seep through foundation cracks and mix within a ventilated but confined structure. Both site-specific and conservative default values were used as input parameters. Neither of these conservative conditions have actually been observed at this site. The predictive model equations and required input parameters are presented in Table 6.4.

The predictive migration model using a subsurface source term based on equilibrium partitioning equations indicates that toluene, ethylbenzene, and xylenes could migrate into ambient air directly above the source area at concentrations that exceed exposure limits established to protect onsite workers (i.e., OSHA TWA PELs). Assuming no concrete apron is present to interrupt flux of volatile COPCs from the land surface, the conservative model predicts that outdoor ambient air concentration of benzene would be less than half of the OSHA TWA PEL for benzene of 3.25 mg/m^3. However, the predicted outdoor concentrations of toluene (17 mg/m^3), ethylbenzene (5.87 mg/m^3), and xylenes (155 mg/m^3) would exceed the respective OSHA TWA PELs (3.83 mg/m^3, 4.41 mg/m^3, and 4.41 mg/m^3, respectively). This means that if the 14-inch reinforced concrete apron is removed from Site ST-27 and underlying native soils are exposed to the atmosphere (e.g., during future construction activities), subsurface sources theoretically could result in outdoor ambient air concentrations in excess of the OSHA TWA PELs for toluene, ethylbenzene, and xylenes.

It is important to note that the equilibrium partitioning equations, which are based on site-specific soil and groundwater sampling data, may overestimate the mass of COPCs present in the vapor phase at Site ST-27. The theoretical vapor-phase concentrations for each of the air COPCs were about 20 percent more than the

TABLE 6.4
MODELING VOLATILIZATION FROM SUBSURFACE MEDIA
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Equations

Equilibrium Partitioning: Vapor Phase above Dissolved Contamination

$C_{v,eq} = (H^{*}C_{w,eq})$

Equilibrium Partitioning: Vapor Phase above LNAPL

$C_{v,eq} = (x_i P_v M_w / RT)$

Equilibrium Partitioning: Vapor Phase in Contaminated Soils

$C_{v,eq} = (HC_{soil}\rho_s)/(\phi_w + k_s\rho_s + H\phi_a)$

Measured Vapor Phase in Soils

$C_{v,eq}$ = Maximum measured soil gas concentration

Effective Vapor Diffusion Coefficient

$D^{eff} = (\phi_a^{3.33}/\phi_T^{3.33})^{*}D_{air} + (1/H)^{*}(\phi_w^{3.33}/\phi_T^{3.33})^{*}D_w$

Maximum Vapor Flux to Open Space

$F_{max} = R_v u_{v,max} C_{v,eq} - (R_v u_{v,max} C_{v,eq})/[1-\exp(R_v u_{v,max} d/D^{eff})]$

Ambient Outdoor Concentration (g/cm³)

$C_{outdoor} = F_{max}L/u_w\delta$

Maximum Vapor Flux to Enclosed Space

$E_{max} = (D^{eff}C_{v,eq}\phi_a^{3.33})/(\phi_T^{2}d)$

Ambient Indoor Concentration (g/cm³)

$C_{indoor} = (E_{max}A_{bldg}F_{crack})/(Air_{exch}V_{bldg}MF)$

Input Parameters

$C_{v,eq}$	Equilibrium vapor concentration (g/cm³)	chemical-specific
H	Henry's law constant (dimensionless)	chemical-specific
$C_{w,eq}$	Equilibrium dissolved concentration (g/ml)	chemical-specific
x_i	Mole fraction of contaminant i	chemical-specific
P_v	Vapor pressure of contaminant i (atm)	chemical-specific
M_w	Molecular weight (g/mol)	chemical-specific
RT	Gas constant*temperature (cm³-atm/mol)	2.44E+04
C_{soil}	Concentration of contaminant in soil (g/g-soil)	chemical-specific
ρ_s	Soil bulk density (g-soil/cm³-soil)	1.7
ϕ_w	Volumetric content of pore water (dimensionless)	0.18
k_s	Sorption coefficient (cm³-H_2O/g-soil)	chemical-specific
ϕ_a	Volumetric content of pore vapor (dimensionless)	0.12
ϕ_T	Total volumetric content in soil (dimensionless)	0.3
D_{air}	Diffusion coefficient in air (cm²-day)	chemical-specific
D_w	Diffusion coefficient in water (cm²/day)	chemical-specific
R_v	Porous media retardation (dimensionless)	$k_s{}^{*}\rho_s$
$u_{v,max}$	Convective transport of vapors (cm/day)	100
d	Distance below ground to source (cm)	152.5
L	Downwind length of source area (cm)	3658
u_w	Wind speed (cm/day)	1.94E+07
δ	Breathing height (cm)	1.89E+02
A_{bldg}	Surface area of building (cm²)	9.29E+06
F_{crack}	Fraction of cracks in foundation (dimensionless)	0.01
Air_{exch}	Air exchanges per day	13,140
V_{bldg}	Volume of building (cm³)	3.00E+09
MF	Mixing factor (dimensionless)	0.5

Compound	H	x_i	P_v	M_w	C_{soil}	D_{air}	D_w	k_s	$C_{w,eq}$	Predicted $C_{v,eq}$	$C_{outdoor}$ (mg/m³)	C_{indoor} (mg/m³)	Measured $C_{v,eq}$	$C_{outdoor}$ (mg/m³)	C_{indoor} (mg/m³)
Benzene	0.232	0.030	0.125	95	3.40E-05	8.04E+03	0.95	0.190	6.9E-06	4.16E-05	1.34E+00	4.67E-06	2.10E-06	6.77E-02	2.36E-07
Toluene	0.265	0.285	0.037	92	3.20E-04	7.34E+03	0.81	0.674	1.0E-05	1.48E-04	1.70E+01	1.52E-05	3.00E-06	3.43E-01	3.08E-07
Ethylbenzene	0.265	0.133	0.009	116	1.50E-04	6.57E+03	0.73	0.477	2.4E-06	7.25E-05	5.87E+00	6.65E-06	1.20E-06	9.72E-02	1.10E-07
Xylenes	0.289	0.554	0.260	106	6.20E-04	6.22E+03	0.73	1.199	6.1E-06	7.62E-04	1.55E+02	6.62E-05	4.10E-06	8.34E-01	3.56E-07

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maximum concentration measured in soil gas near the source area at the site. Table 6.4 compares the theoretical vapor-phase concentrations to the measured maximum soil gas concentrations. If the maximum measured soil gas concentrations are used to estimate outdoor atmospheric exposure-point concentrations, none of the air COPCs are expected to migrate into outdoor air at concentrations that exceed the OSHA TWA PELs. This means that measured vapor-phase concentrations of VOCs in unremediated source area soils are not anticipated to pose an unacceptable inhalation risk to onsite workers even if the concrete apron is removed as part of future land reuse plans.

The 14-inch concrete apron is believed to be effectively interrupting diffusive/convective migration of volatile COPCs from subsurface sources into the outdoor ambient atmosphere. However, the migration model results suggest that some type of subsurface source remediation such as SVE or bioventing may be necessary to ensure that onsite workers are not exposed to toluene, ethylbenzene, and xylenes in outdoor air at concentrations above their respective PELs *if removal of the 14-inch concrete apron is being considered as part of future reuse plans.* As discussed in Section 5.4, concentrations of TVH measured beneath the concrete apron could potentially represent an explosive hazard to Building 575 or subsurface utility systems. Consequently, a soil remediation action involving SVE with off-gas treatment was deemed an appropriate action to take while determining the final corrective action approach for the site. This interim abatement action was designed to reduce the explosive TVH hazard and to minimize the possibility of a significant vapor exposure pathway if the concrete apron is disturbed or removed. Details about this interim action are presented in Sections 7, 8, and 9 of this CAP.

The predictive migration model equations for indoor air demonstrate that subsurface sources at Site ST-27 are not expected to cause indoor air concentrations of the BTEX compounds to exceed the air RBSLs presented in Table 4.4. The predictive migration model indicates that indoor air concentration of each of the BTEX compounds are conservatively expected to be at least an order of magnitude below the SCDHEC (1995) RBSLs for air, which are well below detection limits for most analytical methods. Therefore, no engineered remediation is warranted to prevent migration of volatile COPCs into indoor air at concentrations above the RBSLs. The interim SVE action discussed in Sections 7, 8, and 9 is designed to mitigate potential explosive hazards and outdoor worker exposure, assuming the vapor inhalation pathway could be completed if the 14-inch concrete apron is removed or otherwise disturbed.

6.6.2 Leaching from Contaminated Soils

All of the soil COPCs (i.e., BTEX, naphthalene, chlorobenzene, and 1,3,5-TMB) were identified based on exceedances of Tier 1 RBSLs that are protective of underlying groundwater quality. The RBSLs used in the Tier 1 evaluation are "back calculated" using an equilibrium partitioning calculation to establish residual soil concentrations that prevent leachate generation from sandy soils from exceeding federal MCLs in groundwater (SCDHEC, 1995). The equilibrium partitioning calculation assumes that contaminants either volatilize into pore air volume or desorb from the soil matrix into pore water that is percolating downward through the unsaturated zone to be eventually released into underlying groundwater. Once released into underlying groundwater, the the contaminant is assumed to be subject to both nondestructive (i.e., sorption,

volatilization, dilution with the receiving aquifer) and destructive (i.e., biodegradation) attenuation processes. All of these attenuation processes are incorporated into the RBSLs using a default dilution/attenuation factor (DAF).

To assess the potential for soil COPCs to desorb from "smeared" soils and dissolve into underlying groundwater over time at Site ST-27, a simple predictive leaching model was used. Although the model is similar to the leachability model recommended by the SCDHEC (1995) to establish SSTLs that are protective of underlying groundwater quality, several modifying assumptions had to be incorporated to adequately reflect site conditions. Specifically, the major physical release mechanism for soils at this site is the changing elevation of the groundwater table, rather than downward percolation of precipitation. As discussed previously, the groundwater table fluctuates seasonally, alternately saturating and receding from shallow soils. Residual fuel contamination sorbed onto the soil matrix can be released readily once the soils are saturated. However, once the groundwater recedes from these soils, any residual contamination that did not partition from the soil matrix and dissolve into pore water will be effectively occluded. In addition to providing a release mechanism for sorbed contaminants, the rising groundwater table also likely contributes contaminant mass to the now-saturated soil. Conceivably, LNAPL and dissolved contamination is "smeared" across the soil during the seasonal fluctuations. The impact of LNAPL in terms of contributing contaminant mass to underlying groundwater (and soils) is quantitatively evaluated in Section 6.6.3.

A site-specific equilibrium partitioning relationship was used to model how the soil COPCs are expected to leach from soils seasonally saturated by a rising groundwater table and dissolve into groundwater. A chemical-specific distribution partition coefficient (K_D) that is based on site-specific soil and groundwater analytical data was used to describe how much COPC mass remains associated with the soil matrix and how much COPC mass will dissolve into adjacent pore water. This K_D was incorporated into a a simple batch flushing model in which the total volume of contaminated soil is flushed with rising groundwater for 3 months every year. Contaminants sorbed to the soil matrix are predictively modeled to leach from the soil into the uncontaminated groundwater. Contaminants released into the groundwater also can migrate away or be removed from the release area via the advective bulk movement of groundwater and *in situ* degradation. As contaminant mass is removed from the groundwater in contact with soils, additional contaminant mass can desorb from the soils and dissolve into adjacent pore water.

The site-specific leaching calculations are presented in Table 6.5 and graphically shown in Figure 6.4. As the predictive model results indicate, the shallow soils at Site ST-27 are anticipated to be a significant but diminishing source of soil COPC mass to underlying groundwater for 8 to 10 years. After this time, residual soil COPC concentrations will no longer be a significant source of contaminant mass to underlying groundwater. This leaching approach likely underestimates how long soils could contribute contaminant mass to groundwater since the impact of LNAPL on replenishing soil concentrations is not accounted for in the predictive leaching model. However, the impact of relatively "fresh" LNAPL on underlying groundwater is evaluated in Section 6.6.3. Both of these subsurface sources will be cumulatively incorporated into the simple contaminant transport analytical model presented in Section 6.6.4.

TABLE 6.5
LEACHING OF SOIL COPC MASS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Compound	Maximum Soil Concen. (µg/kg)	Average Soil Concen. (µg/kg)	Site-Specific K_D[a] (L/kg)	Predicted Maximum Groundwater Concentration Measured Near Source[b] (µg/L)				Predicted Average Groundwater Concentration Measured Near Source[c] (µg/L)			
				1995[d]	2000[e]	2005[f]	2010[g]	1995[d]	2000[e]	2005[f]	2010[g]
Benzene	34000	3620	0.19	6979	514	38	2.79	743	55	4	0.30
Toluene	320000	37700	0.67	10445	4990	2384	1139	1231	588	281	134
Ethylbenzene	150000	38200	0.48	2421	635	166	44	617	162	42	11
Xylenes	620000	148000	1.19	6252	4403	3100	2183	1492	1051	740	521
Naphthalene	48000	11800	6.44	276	261	246	233	68	64	61	57
Chlorobenzene	21000	3050	0.24	41	11	3	1	6	2	0.42	0.11
1,3,5-Trimethylbenzene	162000	47400	3.38	431	386	346	310	126	113	101	91

[a] Site-specific partition coefficient based on f_{oc} = 0.005 and K_{oc} values from Montgomery and Welkom (1990) and Wiedemeier *et al.* (1995).

[b] Maximum groundwater concentration estimated by allowing maximum detected soil mass to partition into groundwater as defined by site-specific K_D and accounting for observed dilution; remaining residual soil concentration following 1 leaching event is estimated by subtracting mass leached from original mass (see Appendix E for details).

[c] Average groundwater concentration estimated by allowing average detected soil mass to partition into groundwater as defined by site-specific K_D and accounting for observed dilution; remaining residual soil concentration following 1 leaching event is estimated by subtracting mass leached from original mass (see Appendix E for details).

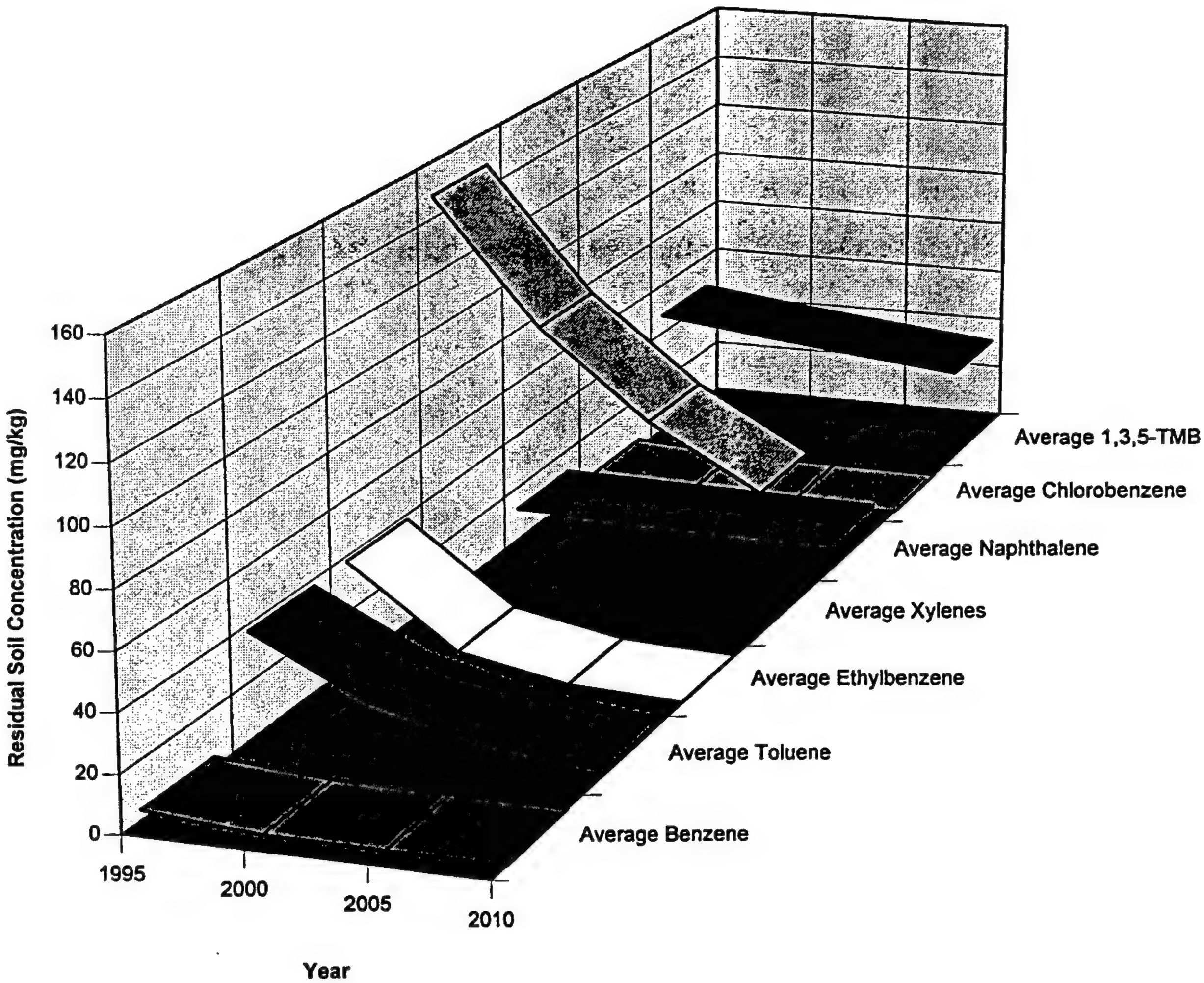
[d] Estimated groundwater concentration in contact with contaminated soils at time = 0 in leaching calculations.

[e] Estimated groundwater concentration in contact with contaminated soils in the year 2000 assuming source area residence time of about 5.3 years due to advective bulk movement and contaminant degradation (see Appendix E).

[f] Estimated groundwater concentration in contact with contaminated soils in the year 2005 assuming source area residence time of about 5.3 years due to advective bulk movement and contaminant degradation (see Appendix E).

[g] Estimated groundwater concentration in contact with contaminated soils in the year 2010 assuming source area residence time of about 5.3 years due to advective bulk movement and contaminant degradation (see Appendix E).

FIGURE 6.4
PREDICTED LOSS OF SOIL COPCs DUE TO LEACHING OVER TIME
SITE ST-27 CORRECTIVE ACTION PLAN RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA



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6.6.3 Dissolution from LNAPL

Relatively unweathered or "fresh" LNAPL thicknesses and oily "sheens" have been identified as a potentially significant source of contaminant mass to groundwater at Site ST-27. OILENS, which is one of the major modules of the EPA's Hydrocarbon Spill Screening Model (HSSM), was used to quantify the dissolution of contaminant mass from LNAPL. The HHSM code was developed by the EPA's Robert S. Kerr Environmental Research Laboratory to aid in estimating the impacts of LNAPL releases on groundwater (EPA, 1994c). The chemical analysis of the LNAPL sample collected at Site ST-27 (Table 5.1) was used to estimate the mass transfer of chemical constitutents in the LNAPL to the groundwater via dissolution caused by advective bulk movement of groundwater. Although OILENS can calculate the mass load to groundwater from infiltrating rainfall based on volume flux (Darcy velocity) of the precipitation influx, this element of the calculation was excluded as a potential release mechanism because the 14-inch reinforced concrete apron prevents significant precipitation infiltration. Consequently, OILENS was used to estimate only the equilibrium concentration for the chemical in contact with groundwater. Relevant explanations of the mathematical basis for OILENS are included in Appendix E (from EPA, 1994c).

LNAPL thicknesses or visible oily sheens were conservatively assumed to impact an area of approximately 1,950 ft^2 in the vicinity of MW20-1. Estimates of the mass fraction of BTEX in the LNAPL were based on analytical data collected at the site (Section 5). The groundwater velocity of 0.035 ft/day was used to develop the most conservative estimate of mass loading. Appendix E presents the model input parameters and calculations related to OILENS.

The model predicted that a maximum of 84 milligrams of total BTEX initially could dissolve into underlying groundwater per day as a result of direct dissolution from LNAPL. This source term estimate is based on the chemical mass measured in the LNAPL collected at MW20-1 during the 1995 sampling event. However, less contaminant mass will be available to act as a continuing source to groundwater as the LNAPL weathers over time. To account for these source weathering effects, OILENS was used to simulate mass loading rates over time. The initial mass of contaminants in the source was sequentially reduced by the mass that had already partitioned from and dissolved into groundwater. As the source of contamination weathered, lower mass loading rates would be expected. Table 6.6 presents the mass loading rates expected over time at Site ST-27 when the effects of weathering are considered. Appendix E shows an example calculation on how weathering impacts were factored into OILENS. Sufficient contaminant mass was measured in the LNAPL at Site ST-27 to act as a continuing source of groundwater contamination for about 10 to 12 years if no engineered source reduction is initiated. After that time, the contaminant mass in the mobile LNAPL would be depleted, provided no additional fuel is introduced into the subsurface.

6.6.4 Transport and Fate Within Groundwater

A simple, one-dimensional analytical model was selected to investigate the transport and fate of dissolved COPCs in groundwater at Site ST-27. The analytical model

TABLE 6.6
DISSOLUTION OF BTEX FROM MOBILE LNAPL
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Year	Benzene Mass (mg/day)[a]	Toluene Mass (mg/day)[a]	Ethylbenzene Mass (mg/day)[a]	Xylenes Mass (mg/day)[a]	Total BTEX Mass (mg/day)[a]
1995	3.38E+04	1.44E+04	8.10E+03	2.83E+04	8.46E+04
1996	2.94E+04	1.27E+04	7.21E+03	2.55E+04	7.48E+04
1997	2.56E+04	1.12E+04	6.42E+03	2.29E+04	6.61E+04
1998	2.23E+04	9.81E+03	5.71E+03	2.06E+04	5.84E+04
1999	1.94E+04	8.64E+03	5.08E+03	1.86E+04	5.16E+04
2000	1.68E+04	7.60E+03	4.52E+03	1.67E+04	4.57E+04
2001	1.47E+04	6.69E+03	4.03E+03	1.50E+04	4.04E+04
2002	1.28E+04	5.88E+03	3.58E+03	1.35E+04	3.58E+04
2003	1.11E+04	5.18E+03	3.19E+03	1.22E+04	3.16E+04
2004	9.65E+03	4.56E+03	2.84E+03	1.10E+04	2.80E+04
2005	8.40E+03	4.01E+03	2.53E+03	9.87E+03	2.48E+04
2006	7.31E+03	3.53E+03	2.25E+03	8.88E+03	2.20E+04
2007	6.36E+03	3.11E+03	2.00E+03	7.99E+03	1.95E+04
2008	5.53E+03	2.73E+03	1.78E+03	7.19E+03	1.72E+04
2009	4.81E+03	2.41E+03	1.58E+03	6.47E+03	1.53E+04
2010	4.19E+03	2.12E+03	1.41E+03	5.83E+03	1.35E+04

[a] Note that, although the dissolution rate is calculated in days, the percent mass loss per year has been normalized to the low groundwater velocities at the site (Appendix E).

ONED3, which is based on the van Genuchten and Alves (1982) solute transport equation, was used to simulate the behavior of benzene in groundwater at the site over time. Benzene was selected as the indicator compound for quantitative analysis for several reasons. First, it is the most mobile of all the groundwater COPCs, which means this chemical will predict the maximum extent of migration under the influence of nondestructive attenuation processes only. Second, the site-specific biodegradation rate calculated for benzene is about equal to the average biodegradation rate for all the COPCs for which biodegradation rates could be estimated (Table 6.2). This means that benzene also is a good indicator of how far dissolved contamination could migrate under the influence of destructive attenuation processes. Third, benzene has the most stringent Tier 1 groundwater RBSL of all the COPCs (and, as will be described in Section 7, also the most stringent Tier 2 groundwater SSTL). Consequently, the chemical fate and transport of dissolved benzene provides a good baseline from which to evaluate the fate and transport of the other groundwater COPCs over time at Site ST-27.

The two primary objectives of this modeling effort were to determine the maximum extent of migration of an indicator groundwater COPC (benzene) and to characterize the anticipated concentrations of the indicator groundwater COPC (benzene) in groundwater as a function of distance and time at the site. The model ONED3 can be easily constructed to include both nondestructive and destructive attenuation processes that may be acting on a specific chemical. An analytical model (rather than a numerical model) was selected as the appropriate model approach for this site based on the preliminary CSM (Section 4). The preliminary CSM concluded that no exposure pathway involving groundwater contaminated by Site ST-27 and offsite receptors is likely to be complete. To verify this assertion, and to aid in establishing POA wells for the site, an analytical model was employed to provide an order-of-magnitude approximation of chemical concentration over time and distance. Due to the types of simplifying assumptions associated with an analytical solution, analytical models generally overestimate the spread of contamination. This makes the model results conservative.

6.6.4.1 Model Overview

The analytical model ONED3 incorporates advection, dispersion, adsorption, and biodegradation to simulate dissolved chemical migration and degradation. The analytical model ONED3 is part of SOLUTE, a program of analytical models for solute transport in groundwater, which was developed by M. Beljin (1989) at the International Groundwater Modeling Center (IGWMC), Butler University, Indianapolis, Indiana. The analytical solution for the ONED3 model includes the nondestructive attenuation processes of advection, dispersion, and adsorption, as well as the destructive attenuation processes of source term degradation and chemical half-life within the saturated media. The analytical model initially was configured to simulate benzene loss from biodegradation using the conservative site-specific biodegradation rates derived in Table 6.2. The average site-specific biodegradation rate constant for benzene of 3.87×10^{-4} day^{-1} was used to simulate the effects of biological processes on contaminant fate over time. This is an important element of this model, because it ensures that biodegradation effects as calculated from actual field-scale evidence are incorporated

into the quantitative chemical fate assessment. A complete description of the analytical model ONED3 developed for this site is included in Appendix E.

The analytical model ONED3 developed for Site ST-27 used site-specific data and conservative assumptions about governing physical, chemical, and biological processes. The use of a one-dimensional model will overestimate the degree of longitudinal (downgradient) migration because the impacts of transverse and vertical migration are not considered. Site data indicate that the dissolved plume is limited to the upper portion of the shallow aquifer, as no elevated concentrations of groundwater COPCs have been detected in wells screened across deeper portions of the shallow aquifer. In addition, although groundwater generally flows to the southwest in the vicinity of Site ST-27, previous potentiometric surface data suggest that the groundwater flow direction is inconsistent/variable (Section 3). Consequently, the one-dimensional model can be used to estimate the maximum extent of travel along a specific flow path, which could vary depending on seasonal flow direction changes.

Other model assumptions focused on defining the effects of remaining contaminant sources on groundwater quality over time at the site. Both contaminated soils, which are periodically saturated when the groundwater table rises, and mobile LNAPL have been identified as significant sources of contaminant mass to underlying groundwater. The mass of benzene that could partition from these subsurface sources and dissolve into and migrate with groundwater over time was based on the source term estimates derived in Sections 6.6.2 and 6.6.3. A significant but diminishing contaminant source term was estimated to persist at the sites for about 10 to 12 years (i.e., 1995 until 2005), assuming no additional contaminant mass or LNAPL is released at the site (Appendix E). After this time, the bulk of benzene mass will have been effectively weathered from both the contaminated soils and mobile LNAPL.

The analytical model ONED3 also was used to simulate the effects of *in situ* soil remediation (i.e., SVE and bioventing) and *in situ* groundwater remediation (i.e., SVE and biosparging). The reduction in the amount of benzene mass that could partition from residual soil contamination into groundwater over time was based on the SVE and bioventing pilot test results presented in Section 8. Approximately 99 percent of the benzene mass could be removed from source area soils at Site ST-27 as a result of 3 to 6 months of SVE followed by 1 to 2 years of bioventing. This decreasing source term rapidly reduces the amount of benzene mass that would otherwise leach from soils and dissolve into underlying groundwater. The amount of dissolved benzene that could be degraded as a result of increasing DO in groundwater by biosparging was estimated by increasing the total expressed assimilative capacity of the groundwater by 0.321 mg/L (equivalent to an average increased DO concentration of 1 mg/L as a result of biosparging). By assuming the site-specific expressed assimilative capacity of 16,928 µg/L total COPC is directly related to an average benzene biodegradation rate of 3.87×10^{-4} day^{-1}, an increase in the source area total expressed assimilative capacity for COPCs by 321 µg/L (by introducing an additional 1 mg/L of DO by biosparging) corresponds to a proportional increase in the benzene source area degradation rate to 4.48×10^{-4} day^{-1}. These specific model results are presented and discussed in Section 9. The model results presented in this section account for the effects of nonengineered processes on contaminant transport and fate.

6.6.4.2 Model Calibration

Part of the modeling strategy for this site was to identify and develop a model that can be used to reasonably simulate observed site conditions. The ideal situation would be to have a limitless supply of site data to use in the creation of a groundwater model that would then generate output that was absolutely representative of site conditions. However, the economics and logistics of collecting enough site data to satisfy each model input parameter would be enormous. Sites with incomplete site data are usually modeled by performing a model calibration rather than returning to the field for additional data to check model predictions. Model calibration is the process of systematically adjusting specific model input parameters within an expected range until the resulting model output is a reasonably good match to observed field conditions. Model calibration is an essential step toward developing an appropriate and defensible mathematical tool to predict contaminant behavior in a complex system (Freeze and Cherry, 1979; National Research Council, 1990).

Both historical analytical data and site data collected the 1995 risk-based investigation were used to calibrate the analytical model ONED3 for Site ST-27. A groundwater flow velocity of 0.035 ft/day and a longitudinal dispersivity value of 21 feet (i.e., equal to one-tenth the length of the dissolved benzene plume) were used to establish flow characteristics. Adsorption of benzene was conservatively incorporated using a site-specific retardation factor of 1.8 (Appendix E). Site-specific data on the benzene biodegradation rate, chemical retardation, longitudinal dispersivity, and source term loading rates (from both soils and mobile LNAPL) were used directly and were not varied during model calibration.

The calibration of the analytical model ONED3 can be evaluated by comparing how closely model predictions match recorded site conditions in terms of contaminant concentration at specific observation points (i.e., monitoring wells). By conservatively assuming the source began in 1988 (i.e., the first year for which site characterization data are available), the 1995 benzene concentrations simulated for the area between MW20-1 and MW20-11, MW20-3, and MW20-15 were in good agreement with the analytical data collected at these sampling locations in 1995. The predicted concentration of benzene for the area between MW20-1 and MW20-11 (the source area) was 6,950 μg/L, which is only slightly more than the maximum detected benzene concentration of 6,900 μg/L measured at MW20-11 in 1995. The predicted 1995 concentration of benzene at MW20-3, which is about 70 feet downgradient from the suspected source area, was 2,100 μg/L. Benzene was detected at well MW20-3 at 2,000 μg/L during the 1995 sampling event. Finally, the predicted concentration of benzene at MW20-15, which is about 250 feet downgradient from the source area, was less than 0.1 μg/L. Similarly, no benzene was detected in this well in 1995. Although the simulated benzene concentrations in the center of the plume were slightly more than observed at the site, the general geometry of the calibrated benzene plume was a good representation of 1995 site conditions. The calibrated analytical model was determined to be a reasonable and conservative estimate of actual field conditions, and sufficient to be used to develop predictive chemical fate estimates.

6.6.4.3 Model Results

The analytical model was run under three different scenarios to assess the impact of different types of remedial approaches on the extent of benzene migration and persistence in groundwater at Site ST-27. The first model simulated natural chemical attenuation of dissolved benzene with no source reduction other than implementation of the planned SVE interim action. The second model simulated natural chemical attenuation of dissolved benzene supplemented by both SVE followed by bioventing of source area soils. The results of this second model will be presented in Section 9 to compare the relative merits and disadvantages of implementing low-cost *in situ* soil source reduction technologies at Site ST-27. The third model simulated natural chemical attenuation of dissolved benzene supplemented by both SVE and biosparging of source area groundwater/soils. The results of this model also will be presented in Section 9 to compare the relative merits and disadvantages or implementing *in situ* groundwater treatment to expedite remediation of the site. The model results for each of the three different scenarios were used to:

- Establish the plume core concentration that will result in no additional downgradient migration of the leading edge of the dissolved plume;
- Identify POAs; and
- Estimate the time required to uniformly reduce onsite concentrations to specified "bench mark" levels (e.g., Tier 1 RBSLs, Tier 2 SSTLs).

Figure 6.5 presents the expected extent of benzene migration in the shallow aquifer in 1998, 2003, 2010, and 2017 if no engineered source reduction is implemented at the site. Because of the presence of elevated concentrations of soil COPCs and small amounts of relatively unweathered LNAPL, the conservative model predicts that dissolved benzene concentrations in the source area should continue to increase until the year 2003. The model projects a maximum dissolved benzene concentration of 7,450 μg/L, in comparison to the maximum concentration of 6,900 μg/L measured in 1995. Once the plume core concentration of benzene drops below 4,500 μg/L, the plume is expected to stabilize (i.e., no further increases in plume size will occur). Actually, the plume appears relatively stable by the year 2003, although the plume core concentration of benzene is not expected to decrease below the 4,500 μg/L level until the year 2005. Once the soil and LNAPL sources have been "weathered", plume core concentrations decrease relatively rapidly. By the year 2017, dissolved benzene concentration are expected to be reduced by more than 95 percent at all sampling locations. The maximum concentration of benzene expected to persist at the site at this time is about 240 μg/L. Although not shown on Figure 6.5, dissolved benzene concentrations are expected to be reduced below the Tier 1 RBSL of 5 μg/L by the year 2028.

Although the fate and transport of the other groundwater COPCs were not simulated using the analytical model ONED3, a qualitative assessment can be made based on the results of the simulation of the benzene contamination and chemical-specific migration and biodegradation rate estimates. Table 6.1 presents the expected contaminant velocities and travel distances over a 7-year period (i.e., 2,615 days) if only nondestructive attenuation processes are considered. As expected, benzene is the most mobile of all the groundwater COPCs; benzene is expected to migrate 94 percent

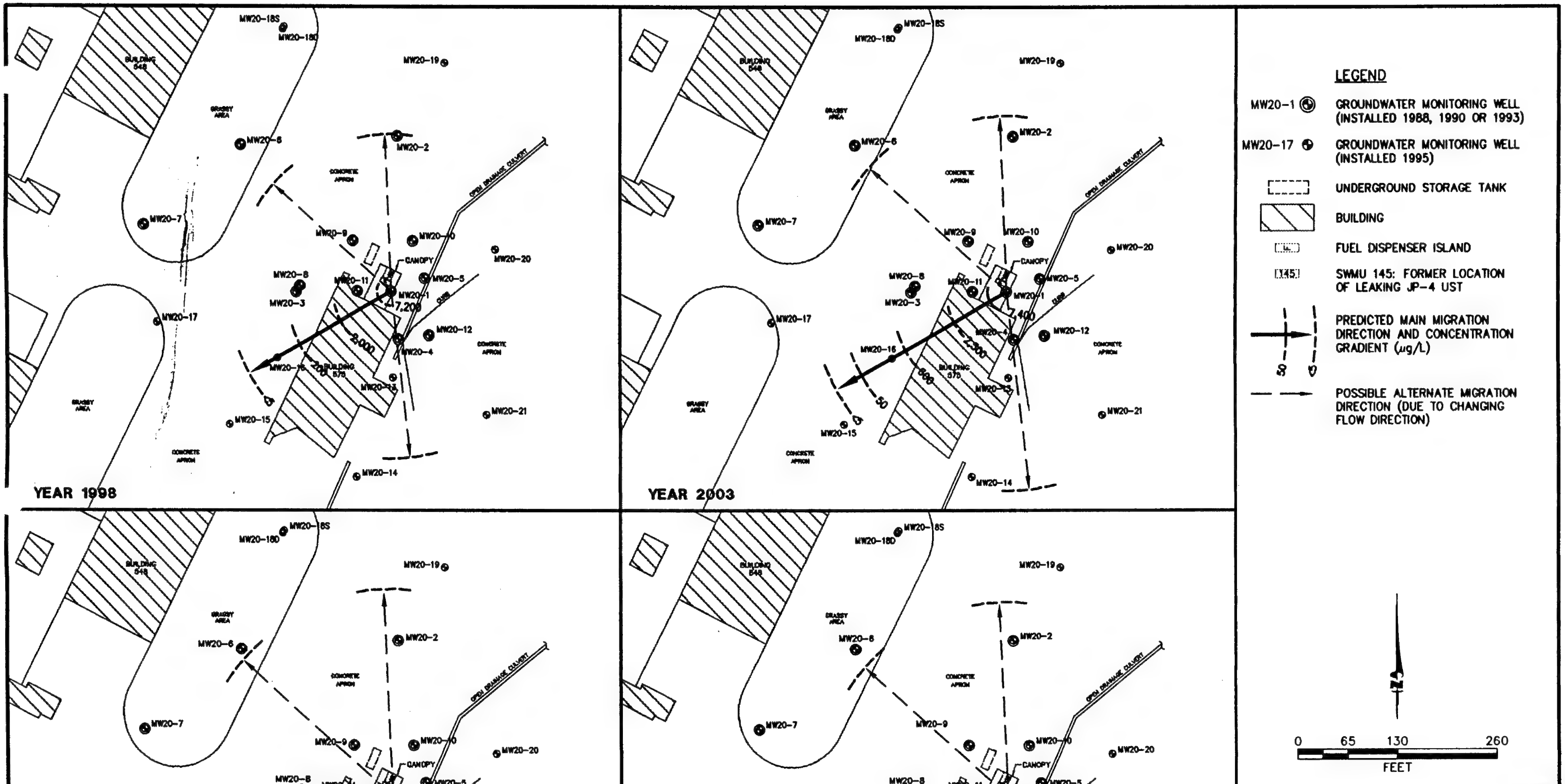

FIGURE 6.5

PREDICTED EXTENT OF DISSOLVED BENZENE NATURAL ATTENUATION ONLY

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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further than naphthalene. Additionally, the site-specific biodegradation rate estimates (Table 6.2) suggest that benzene biodegrades about 30 percent more slowly than toluene but 80 percent more rapidly than naphthalene. Although the maximum concentration of toluene was about 30 percent higher than the maximum concentration of benzene (Figure 5.6), toluene migrates almost twice as slow as benzene and biodegrades more than 30 percent faster than benzene at this specific site. Consequently, toluene is not expected to migrate much further than that predicted for dissolved benzene, and the faster degradation rates should be sufficient to minimize its persistence in onsite groundwater. Although the degradation rates for naphthalene have been estimated to be slower than the degradation rate of benzene, naphthalene is far less mobile than benzene. Elevated concentrations of naphthalene were only detected near the source area (Figure 5.7), and the conservative migration estimates indicate that naphthalene should migrate less than 65 feet over the next 20 years. It is unlikely that naphthalene will migrate to onsite, downgradient wells (i.e., MW20-14, MW20-15, and MW20-17) at detectable concentrations.

There are no historical data available to observe contaminant reduction trends for the TMB isomers and chlorobenzene. However, the migration rate for each of these compounds falls within the range bounded by benzene and naphthalene. Additionally, literature-reported values for degradation rates for these compounds are bounded by the literature-reported values for degradation rates for benzene and naphthalene.

On the basis of these simulations, it appears that natural hydrodynamic and chemical attenuation processes are sufficient to inhibit further benzene migration from Site ST-27 without engineered remediation. In fact, existing wells at the site appear to be well placed to be used as POA wells. For example, benzene is not expected to be detected at concentrations above the Tier 1 RBSL at several onsite, downgradient wells (i.e., MW20-14, MW20-15, and MW20-17). However, the potential for elevated concentrations of benzene to persist in onsite groundwater for more than 20 years may result in significant monitoring commitments. To minimize monitoring commitments (and prevent continuing increases in plume size and concentration), the conservative model results imply that engineered source or groundwater remediation may be desirable at Site ST-27 to prohibit future releases of contaminant mass to underlying groundwater. The anticipated effects of engineered source reduction on dissolved benzene at this site is presented in Section 9.

6.7 CONCLUSIONS

This section has focused on explaining how and why air, soil, and groundwater COPCs can be effectively attenuated by natural nondestructive and destructive processes. The important findings of this section are summarized as follows:

- Measured subsurface vapor concentrations of air COPCs (i.e., the BTEX compounds) do not pose an inhalation hazard to onsite workers. However, measured concentrations of contaminants in soil, LNAPL, and groundwater theoretically could pose an inhalation hazard to onsite outdoor *workers if the concrete apron is removed during future land use activities.*

- Soil COPCs appear to be effectively attenuated based on available site data, although site-specific leaching calculations indicate that contaminants are expected to slowly partition from periodically saturated deeper vadose zone soils and saturated soils for the next 8 to 10 years.

- OILENS model results indicate that small quantities of LNAPL will act as a significant but diminishing contaminant source to underlying groundwater for about 10 to 12 years.

- Site-specific biodegradation rate estimates and site-specific theoretical assimilative capacity estimates confirm that measured concentrations of groundwater COPCs in saturated soil and groundwater eventually can be completely biodegraded by natural processes.

- Available geochemical data indicate that groundwater COPCs are biodegrading in saturated soils and groundwater at Site ST-27 via oxygen reduction, manganese reduction, ferric iron reduction, sulfate reduction, methanogenesis, and possibly reductive dehalogenation at rates similar to those reported in the technical literature.

- The analytical model ONED3 for indicator compound benzene suggests that, although the center of the dissolved plume could increase in concentration and the plume boundary could expand slightly over the next few years (i.e., until the year 2003 or 2005), natural chemical attenuation processes will be sufficient to prevent significant migration of dissolved contamination.

- Even in the absence of SVE or bioventing, model simulations suggest that benzene concentrations in the plume core will decrease below the level required to prevent further increases in plume size or concentration by the year 2005. Additionally, dissolved benzene concentrations should be reduced by more than 95 percent by the year 2017, when no benzene should persist in onsite groundwater at concentrations above 240 μg/L. Benzene should be reduced below the Tier 1 RBSL of 5 μg/L at every sampling location by the year 2028 even if no additional engineered action other than the planned SVE interim action is implemented at the site.

This quantitative chemical fate assessment demonstrates that, although the dissolved plume could increase in size and concentration over the next few years, natural chemical attenuation processes will eventually be sufficient to achieve contaminant mass reductions and minimize contaminant mobility. However, it may be desirable to implement some level of source reduction at this site to limit monitoring requirements (and prevent additional adverse impacts to groundwater quality in the source area from soil and LNAPL sources). Because measured site concentrations currently exceed Tier 1 RBSLs, this quantitative chemical fate assessment will be incorporated into a Tier 2 evaluation (Section 7). The purpose of this Tier 2 evaluation is to evaluate whether current levels of site contamination pose an unacceptable risk to potential receptors given the current and proposed use of the impacted resources and to establish Tier 2 SSTLs. The conclusions of the Tier 2 evaluation will be used to evaluate the type, magnitude, and timing of remediation required to protect potential onsite receptors.

SECTION 7

TIER 2 ANALYSIS AND IDENTIFICATION OF FINAL CHEMICALS OF CONCERN

7.1 OBJECTIVE OF SITE-SPECIFIC EVALUATION

The Tier 1 analysis conducted in this CAP (Section 4) identified the BTEX compounds, naphthalene, chlorobenzene, and 1,3,5-TMB as potential leachate COPCs in soils; benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and *cis*-1,2-DCE as COPCs in groundwater; and the BTEX compounds as COPCs in air. These analytes were then evaluated in detail to better define/assess the potential adverse health effects they may cause in current or future human receptors.

The Tier 1 screening process is considered protective of human health because the Tier 1 risk-based screening criteria are based on conservative "reasonable maximum exposure" (RME) assumptions. As stated in Section 4, the Tier 1 screening criteria are defined by SCDHEC (1995) and USEPA (1996) as nonsite-specific or generic risk-based screening levels. However, analytes identified as COPCs in Section 4 of this CAP (i.e., analytes with representative site concentrations exceeding Tier 1 RBSLs) should not automatically be considered to be present at ST-27 at levels that pose unacceptable threats to human health. Rather, these exceedances of the screening criteria indicate further evaluation under more site-specific exposure scenarios is warranted.

This second phase of evaluation is described as a Tier 2 evaluation (SCDHEC, 1995) and consists of three steps: 1) establishing an exposure point(s) (see Section 7.1); 2) establishing site-specific points of compliance (or, as is the case for Site ST-27, POAs) (see Section 6.6.4.3); and 3) calculating the corresponding site-specific risk-based concentrations for the COPCs applicable at the POAs and in the source area based on the measured and predicted attenuation of the COPCs away from the source area (see Section 7.3 and Appendix F). Not explicitly discussed in the SCDHEC (1995) guidance is the importance of reevaluating exposure pathway completion during the Tier 2 evaluation. The revised CSM for Site ST-27, which is presented in Section 7.2, identifies only those receptors and exposure pathways that realistically may be completed under actual current or hypothetical future exposure scenarios, considering land uses and the results of the chemical fate and transport assessment presented in Section 6.

Section 6 presented the results of fate and transport modeling used to predict the attenuation of the COPCs migrating away from the source area and to develop POAs as part of the Tier 2 evaluation. The risk-based tiered approach is culminated in this section by comparing appropriate site concentrations (observed current, and if appropriate, predicted future) to realistic matrix-specific SSTLs at receptor exposure points (e.g., at the source area or some distance downgradient or downstream from the source, defined as the POA). These SSTLs are described by SCDHEC (1995) as the Tier 2 risk-based criteria, and differ from the generic RBSLs in that the conservative exposure assumptions used to derive the generic RBSLs (e.g., exposure duration of 25 years) are replaced with more realistic site-specific exposure assumptions (e.g., exposure duration of 1 year). It is important to emphasize that the Tier 2 SSTLs are based on achieving levels of human health protection similar to those of the generic RBSLs (i.e., the site-specific criteria are based on a carcinogenic target risk limit of 10^{-6} and a noncarcinogenic hazard quotient of ≤ 1), and are considered adequately conservative and consistent with SCDHEC (1995) and USEPA (1996) recommended practices. These Tier 2 SSTLs may be negotiated as the alternate compliance goals for Site ST-27 if it is determined that attainment of the generic cleanup criteria is not appropriate, feasible, or cost effective. The SSTLs also can be used to confirm that no unacceptable exposures are likely to occur at Site ST-27 until either site-specific or generic cleanup criteria can be attained, either through engineered remediation or natural chemical attenuation processes.

One of the primary site-specific considerations that can be incorporated into development of the SSTLs is the demonstrated and predicted degree of attenuation of COPCs in affected environmental media. As mentioned above, the comprehensive chemical fate assessment, which emphasizes documenting bioattenuation of the COPCs, concluded that natural chemical attenuation processes are effectively minimizing the mass and mobility of fuel hydrocarbon COPCs in soils, groundwater, and air and that these processes are expected to be sufficient to prevent COPC migration beyond a 250-foot radius from Site ST-27. Based on this information, it can be concluded that migration of COPCs off Base will not occur. However, as discussed in Section 6.6.4, the conservative analytical model predicts that, without some type of engineered remediation of subsurface sources (i.e., mobile LNAPL and contaminated soils), dissolved COPC concentrations are expected to increase by about 8 percent from the levels measured in 1995 within the source area until the year 2003 or 2005 (Figure 6.4). In addition to increases in dissolved COPC concentrations in the source area, the conservative analytical model predicts that the dissolved plume could migrate at detectable concentrations an additional 60 feet downgradient from its current position. After the year 2005, natural attenuation processes are anticipated to gradually reduce groundwater COPC concentrations and minimize additional downgradient migration. These model results suggest that, although offsite exposure pathways involving groundwater will remain incomplete as a result of natural chemical attenuation processes, subsurface sources will continue to cause adverse impacts to underlying groundwater for 8 to 10 years and significant COPC mass will persist in onsite groundwater for at least 30 years (i.e., above Tier 1 RBSLs until the year 2028).

Because several fuel-related hydrocarbons were measured in soil, groundwater, and soil gas at Site ST-27 at concentrations above the applicable generic RBSLs, active remediation measures such as SVE are being considered as interim actions, as required

by SCDHEC (1995), to prevent any potential imminent, unacceptable exposures that could occur at or near the source area (e.g., high concentrations of VOCs in the source area that could contribute to explosive conditions and potential outdoor inhalation hazards if the concrete apron is removed). Section 8 describes ongoing and planned interim actions. In addition to interim actions, the presence of various analytes at concentrations above the applicable generic RBSLs also justifies the need for a Tier 2 evaluation to assist in the development of corrective actions that can achieve the desired level of risk reduction at the site.

In summary, the objectives of developing SSTLs that include exposure assumptions more representative of actual site conditions are 1) to determine whether current or predicted future site concentrations of COPCs present an unacceptable risk to current and future receptors in the absence of engineered remediation other than interim action, (given the type and nature of exposures likely to occur near the source area); and 2) to provide a mechanism or reference to assess the cost and time required to lower site concentrations to achieve adequate risk reduction at the site.

The impact of natural chemical attenuation processes on COPC concentrations at potential exposure points and realistic assumptions about likely exposure routes were incorporated into the SSTLs. If current and predicted future site concentrations are below the SSTLs, natural chemical attenuation supplemented with land use controls and long-term monitoring would afford the desired level of protectiveness (i.e., carcinogenic and noncarcinogenic risks would be below the threshold risk levels established by SCDHEC and USEPA). If the current or predicted future site concentrations exceed the SSTLs, more active remediation techniques such as engineered groundwater/soil remediation to supplement natural chemical attenuation processes would be considered. Thus, the SSTLs may be considered as proposed alternate cleanup criteria for Site ST-27.

7.2 REVISED CONCEPTUAL SITE MODEL REVIEW

The preliminary CSM presented in Section 4 was used to qualitatively identify potential human and ecological receptors that may be exposed to site-related contaminants, and to define the types of these potential exposures to contaminants at and migrating from Site ST-27 (Figure 4.2). The preliminary CSM describes onsite release points, the affected physical media, the types of contaminant transport and fate mechanisms that may be involved at the site, each group of potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. This CSM was used to identify which of the exposure assumptions used to develop generic cleanup criteria most closely approximates site conditions. The exposure assumptions incorporated into the generic RBSLs were identified as generally representative of the types of exposure that could occur at Site ST-27, but perhaps greatly overestimated the magnitude of exposure specific to current and expected future site conditions. In some cases, exposure pathways identified in the preliminary CSM were not necessarily realistic, but were included in the Tier 1 evaluation to be conservative. As an example, the inclusion of an exposure pathway to off-Base potable groundwater users prompted the use of risk-based groundwater concentrations (i.e., RBSLs) that are based on tap-water exposure assumptions. The preliminary CSM exposure pathways are reevaluated in this section using more

reasonable land use assumptions and the Tier 2 chemical fate information presented in Section 6. It is important to emphasize that the purpose of using the preliminary CSM and the conservative, nonsite-specific RBSLs to identify COPCs was to ensure that all subsequent assessment activities beyond the Tier 1 screening evaluation address the full range of contaminants that may require some type of remediation.

As mentioned earlier in Section 7.1, the revised CSM for Site ST-27, which is presented in Figure 7.1 and briefly reviewed in the following subsections, identifies only those receptors and exposure pathways that realistically may be involved in actual current or hypothetical future exposures. The outcome of the chemical fate assessment presented in Section 6 and the types of exposures likely to occur at this industrial site are reflected in this revised CSM. Justification for each site-specific exposure assumption is provided in subsequent discussions.

7.2.1 Revised Conceptual Model

7.2.1.1 Sources, Affected Media, Release Mechanisms, and Contaminant Environmental Transport

The likelihood of release from a source, the nature of the contaminants involved, the affected environmental media, and the probable magnitude of their release all are included in the revised CSM (Figure 7.1). As described in the preliminary CSM (Figure 4.2), the most likely sources of site-related chemical contamination include releases from several in-place and now-removed USTs used to store JP-4 (historically) and JP-8 (currently) jet fuels, MOGAS, and diesel fuel to support aircraft operations at the Base. Historical (and potentially recent releases) from leaking USTs and fuel transfer lines have contaminated site soil, soil gas, and groundwater with fuel hydrocarbons. In addition to site-related fuel contamination, relatively low concentrations of nonfuel organic compounds from adjacent SWMUs have been measured in soil and groundwater at and immediately upgradient from Site ST-27.

The predominant ongoing release mechanisms for both air and groundwater COPCs are volatilization and leaching from contaminated soils and mobile LNAPL. Simple equilibrium partitioning equations and soil gas sampling data were both used to assess the potential for subsurface sources to contribute significant VOC mass to indoor or outdoor breathing zones. As discussed in Section 6.6.1, volatilization from subsurface sources could theoretically pose an inhalation risk to onsite outdoor workers if the concrete apron is removed as part of future land use plans. However, no inhalation risk is predicted for outdoor workers if actual soil gas sampling data are used to represent potential vapor-phase onsite sources. No air COPC is predicted to migrate into indoor breathing zones at concentrations above the Tier 1 RBSLs (SCDHEC, 1995). Leaching from mobile LNAPL and contaminated soils, which are repeatedly "smeared" with mobile LNAPL, is expected to be a significant release mechanism to groundwater for about 10 to 12 years (i.e., by the year 2007). The very low groundwater seepage velocity (i.e., 0.017 ft/day) and the potential for multi-directional groundwater flow result in a lengthy groundwater residence time near the suspected source area. These hydrogeologic conditions act to minimize both the horizontal migration and destructive attenuation of the dissolved plume. Although only minimal downgradient migration of contaminants is possible, the rate of biodegradation of

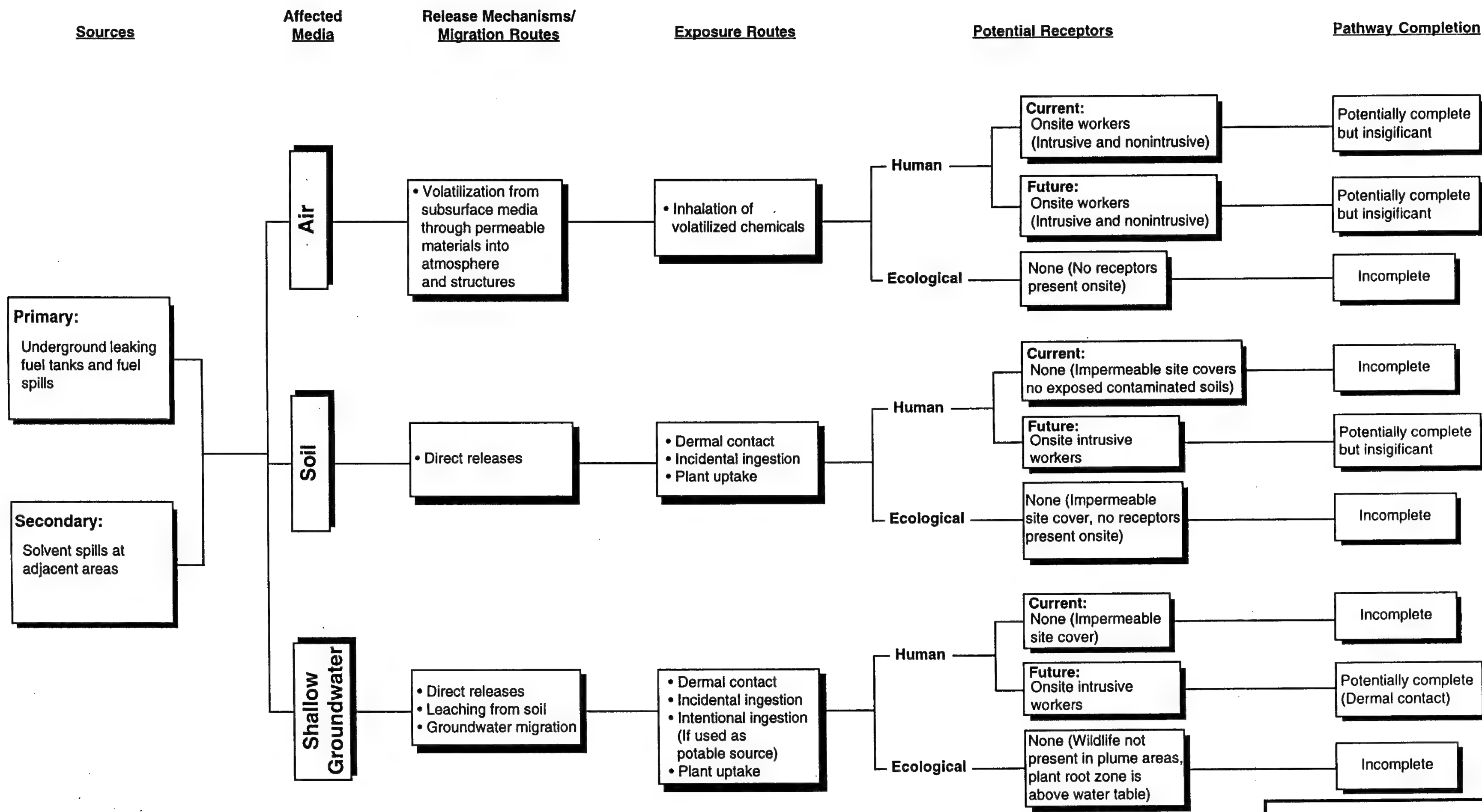

FIGURE 7.1

REVISED CONCEPTUAL SITE MODEL

Site ST-27 Corrective Action Plan
Risk-Based Approach to Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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dissolved COPCs is reduced because of the absence of a significant influx of electron acceptors into the plume core. However, as the analytical model developed in Section 6.6.4 shows, the rates are sufficient to limit plume migration by the year 2005, and reduce groundwater COPC concentrations by about 95 percent by the year 2017. No significant plume migration is expected based on conservative modeling results.

7.2.1.2 Potentially Exposed Receptors, Exposure Points, and Exposure Routes

The revised CSM for Site ST-27 also refines the identification of potentially exposed receptor populations, receptor exposure-points, and exposure routes for realistic scenarios based on specific site ST-27 conditions. These components better reflect the likelihood and extent of human or ecological receptor contact with site-related contaminants. As described in Section 3, Site ST-27 is an operational aircraft equipment support facility within an industrial area of an active Base. Potential receptor groups are limited to onsite intrusive and nonintrusive workers; there are no completed pathways to offsite receptors (see Section 6). The activities of onsite nonintrusive workers are generally confined to the paved areas of the site, and even incidental contact with contaminated soil or groundwater is unlikely. Consequently, no exposure of current onsite nonintrusive workers to these contaminated site media is occurring or is likely to occur in the future. Furthermore, the industrial nature of the site, which includes concrete and asphalt driveways and parking areas, hangar facilities, and chain link fencing to limit access, precludes the existence of suitable wildlife habitat. No resident ecological receptors were identified for which soils and/or groundwater are likely contaminant exposure media. No exposure pathways involving potential offsite receptors are or will be complete based on the outcome of the quantitative chemical fate assessment presented in Section 6.

Using the most conservative exposure assumptions appropriate for Site ST-27, the only realistic receptor that is likely to become exposed to contaminants at Site ST-27 is the onsite intrusive worker involved in demolition, removal, and/or construction activities. As an example, onsite intrusive workers could be exposed to impacted environmental media (specifically shallow soils and groundwater) during excavation activities at and immediately downgradient from Site ST-27. It is important to emphasize that based on comparisons of the maximum site soil chemical concentrations to the RBSLs for ingestion and dermal exposure to soil (Table 4.5), risk from direct exposure to soils is negligible (i.e., below the Tier 1 RBSLs). However, worker exposure to groundwater is reexamined in the Tier 2 evaluation because maximum groundwater concentrations exceed ingestion-based RBSLs (albeit for unrestricted or potable-based use assumptions). Additionally, inhalation of VOCs (partitioning from either contaminated soil or groundwater) in ambient air at the site theoretically could result in a completed pathway for the onsite intrusive worker once the concrete apron is disturbed or removed. However, based on the modeling conducted in Section 6 using measured soil gas concentrations, this pathway can be assumed to be negligible. In addition, incidental ingestion of groundwater by the onsite intrusive worker was

eliminated from further consideration. It is not reasonable to assume that intrusive workers could actually consume (incidentally) a significant amount of contaminated groundwater during excavation activities.

7.2.2 Summary of Completed Exposure Pathways

Given the current and planned future uses of Site ST-27 and the outcome of the Tier 2 quantitative chemical fate assessment presented in Section 6, only onsite intrusive workers could be exposed to site-related contamination during excavation activities (see Figure 7.1). Therefore, the only health-based Tier 2 SSTLs developed for Site ST-27 are those designed to protect hypothetical onsite intrusive workers from carcinogenic risks and noncarcinogenic hazards in the event that they were incidentally exposed to site-related contamination in excess of the generic Tier 1 RBSLs presented in Tables 4.1 through 4.2. In addition to the development of Tier 2 concentrations specific to the onsite intrusive worker, SSTLs for capillary fringe soils were "back calculated" from the groundwater SSTLs to reassess the potential for onsite soils to generate COPC leachate at concentrations equal to or greater than the groundwater SSTLs. Further, SSTLs for groundwater for the plume core that prevent plume expansion were estimated from the analytical model results. These SSTLs define the maximum plume core concentration at which no further downgradient plume migration will occur due to the effects of nondestructive and destructive chemical attenuation processes.

7.3 DEVELOPMENT OF SITE-SPECIFIC TARGET LEVELS (SSTLS)

The SCDHEC (1995) has not defined an algorithm for dermal contact with chemicals in water. Consequently, the algorithm used to calculate the groundwater SSTL assuming incidental dermal contact only is based on the general absorption intake equation for dermal contact with chemicals in water developed by USEPA (1989). In addition to the exposure route considered in the SSTL calculation, two other site-specific exposure assumptions (i.e., exposure frequency, exposure duration) were used (see SSTL equations in Appendix F). An exposure frequency of 250 days per year was assumed to be reasonably conservative for onsite workers engaged in highly intrusive activities at Site ST-27, such as the demolition of Building 575 and/or the removal of the site's UST system. The value of 250 days per year is based on a 5-day work week with two weeks of vacation each year. An exposure duration of 1 year was assumed to be a conservative (health protective) exposure duration for intrusive onsite workers, considering the size and current and anticipated future operational activities occurring at Site ST-27. All other exposure variables used to calculate the groundwater SSTLs are USEPA (1989 and 1991c) default values. COPC toxicity values used in the SSTL derivations are based on toxicity data reported in the Integrated Risk Information System (IRIS) (Micromedex, Inc., 1996) or used by EPA Region VIII (1996) to derive the generic RBSLs. Appendix F presents the exposure assumptions and derivation of the SSTLs for Site ST-27.

7.3.1 SSTLs for Soil

Table 7.1 presents the potential soil leaching SSTLs and the generic soil leaching RBSLs for the soil COPCs for Site ST-27. The soil leaching SSTL is based on site-

TABLE 7.1
SITE-SPECIFIC TARGET LEVELS FOR SOILS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Soil COPC	Units	Soil Leaching SSTL to Prevent Plume Expansion[a]	Soil Leaching SSTL to Attain RME Health-Based SSTL[b]	Soil Leaching SSTL to Attain CT Health-Based SSTL[c]	Soil Leaching SSTL to Attain Tier 1 RBSLs[d]	Soil Leaching RBSL[e]
Benzene	mg/kg	21.9	1.2	3.1	0.0	0.007
Toluene	mg/kg	198.0	268.3	355.3	22.8	1.7
Ethylbenzene	mg/kg	97.2	157.7	208.8	43.6	2
Total Xylenes	mg/kg	393.2	--	--	991.7	44
Naphthalene	mg/kg	305.5	4.4	58.8	4.4	0.2
Chlorobenzene	mg/kg	13.6	164.4	218.0	19.9	0.48
1,3,5-Trimethylbenzene	mg/kg	95.2	269.6	357.2	112.7	0.21

NOTE: Derivation of SSTLs presented in Appendix E as part of chemical fate assessment.

a/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration to prevent expansion of plume boundary was estimated using analytical model ONED3 (Section 6.6.4). Used target groundwater concentration to "back calculate" groundwater protective SSTL.

b/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration = RME health-based groundwater SSTL (worker dermal exposure to groundwater) was used to "back calculate" groundwater protective SSTL.

c/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration = CT health-based groundwater SSTL (worker dermal exposure to groundwater) was used to "back calculate" groundwater protective SSTL.

d/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration = Tier 1 RBSL for groundwater (worker unrestricted use of groundwater) was used to "back calculate" groundwater protective SSTL.

e/ Tier 1 soil leaching RBSLs provided for comparison only.

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specific soil/groundwater partitioning data and an equilibrium partitioning relationship based on contaminant release via rising and falling groundwater table rather than infiltrating precipitation. The soil leaching RBSLs defined by SCDHEC (1995) are based on a DAF of about 8 for sandy soils. The DAF of 8 was estimated using a soil leachability model based on an equilibrium sorption/desorption relationship and release via infiltration. Similarly, soil leaching RBSLs from USEPA were adjusted to a DAF of 8 (rather than a published, generic value of 10). The soil leaching SSTLs are chemical-specific in terms of how well each chemical is attenuated in site soils (i.e., a generic DAF that applies to all chemicals is not used). Appendix E presents the simple algorithms used to derive the soil leaching SSTLs. Soil leaching SSTLs are "back calculated" from the health-based groundwater SSTL (Table 7.2) and the generic industrial RBSL for groundwater.

7.3.2 SSTLs for Groundwater

Table 7.2 presents both the groundwater SSTLs and generic groundwater RBSLs defined by the SCDHEC (1995) that are based on unrestricted water use. Note that RME and Central Tendency (CT) SSTLs are presented. The RME SSTL is designed to illustrate "high-end" exposure, whereas the CT SSTLs better illustrate mean exposure. The CT SSTLs are provided for comparative purposes only but do provide a less than maximum exposure-type perspective. The groundwater RME SSTLs are health-based values calculated to protect onsite intrusive workers from health risks associated with dermal exposure to chemical contamination in groundwater. As stated earlier, the generic health-based RBSLs are calculated assuming purposeful ingestion of onsite groundwater by onsite workers under residential-type exposure conditions (i.e., 30 year exposure duration, 2 liters per day consumption rate, etc.). Therefore, the generic residential health-based cleanup criteria are provided only as "benchmark" values identifying the risk-based concentration where no land use restrictions would be necessary.

7.4 COMPARISON OF EXPOSURE-POINT CONCENTRATIONS TO SSTLS

The maximum detected concentration of soil and groundwater COPCs were conservatively assumed to represent the current and future exposure-point concentrations at Site ST-27. However, it is important to note that the Tier 2 chemical fate assessment demonstrates that site concentrations will decrease to below the health-protective SSTLs by the year 2017 as a result of interim action SVE and nondestructive and destructive natural chemical attenuation processes. In addition, the maximum detected site concentration most likely does not represent the true exposure-point concentration for future workers. The future exposure-point concentrations, should onsite workers engaged in highly intrusive activities, are expected to be significantly lower than the maximum concentrations observed during the 1995/96 sampling events.

Table 7.3 compares the average detected soil COPC concentrations to the soil leaching SSTLs. (Note that this comparison is similar to the Tier 1 evaluation of site

TABLE 7.2

SITE-SPECIFIC TARGET LEVELS FOR GROUNDWATER

SITE ST-27 CORRECTIVE ACTION PLAN

RISK-BASED APPROACH TO REMEDIATION

CHARLESTON AFB, SOUTH CAROLINA

COPC	Units	Tier 2 RME Health-Based SSTLs[a/]	Tier 2 CT (Average) Exposure Health-Based SSTLs[b/]	Tier 1 SCDHEC/EPA Generic RBSLs[c/]
Benzene	µg/L	240[d/]	640[d/]	0.36
Ethylbenzene	µg/L	2,500	3,400	700
Toluene	µg/L	8,800	12,000	750
Naphthalene	µg/L	260	330	25
Chlorobenzene	µg/L	320	430	39
1,2,4,-Trimethylbenzene	µg/L	720	950	300
1,3,5-Trimethylbenzene	µg/L	720	950	300
cis-1,2-Dichloroethene	µg/L	2,000	2,600	61

NOTE: Derivation of SSTLs presented in Appendix F.

[a/] RME SSTLs are designed to protect onsite intrusive workers from unacceptable exposure due to incidental exposure via dermal contact with dissolved chemicals in groundwater using site-specific exposure assumptions (carcinogenic value for benzene; noncarcinogenic values for all other COPCs).

[b/] Average or CT SSTLs (i.e., SSTLs based on average exposure assumptions) are provided for comparison with RME SSTLs for onsite intrusive workers exposed via incidental dermal contact with dissolved chemicals in groundwater (carcinogenic value for benzene; noncarcinogenic values for all other COPCs).

[c/] SCDHEC (1995)/EPA Region VIII (1996) (the lesser of the two values) generic RBSLs would be protective of onsite workers whose drinking water comes from an onsite groundwater source.

[d/] Health-based SSTL values for benzene (a carcinogen) are based on target risk levels of 10^{-6} (see Appendix F for calculated SSTLs values based on target risks of 10^{-4} and 10^{-5}).

TABLE 7.3
COMPARISON OF ANALYTICAL SOIL DATA TO SOIL LEACHING SSTLs
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Soil COPC	Units	Maximum Detected Concentration[a]	Calculated Average Concentration[b]	Soil Leaching SSTL to Prevent Plume Expansion[c]	Soil Leaching SSTL to Attain RME Health-Based SSTL[d]	Soil Leaching SSTL to Attain CT Health-Based SSTL[e]	Does Max. Conc. Exceed Most Stringent SSTL?	Does Avg. Conc. Exceed Most Stringent SSTL?
Benzene	mg/kg	34	3.62	21.9	1.2	3.1	YES	YES
Toluene	mg/kg	320	37.7	198.0	268.3	355.3	YES	NO
Ethylbenzene	mg/kg	150	38.2	97.2	157.7	208.8	YES	NO
Total Xylenes	mg/kg	620	148	393.2	--	--	YES	NO
Naphthalene	mg/kg	48	11.8	305.5	4.4	58.8	YES	YES
Chlorobenzene	mg/kg	21	3.05	13.6	164.4	218.0	YES	NO
1,3,5-Trimethylbenzene	mg/kg	162	47.4	95.2	269.6	357.2	YES	NO

NOTE: Derivation of SSTLs presented in Appendix E as part of chemical fate assessment.

a/ Maximum concentrations were obtained from the 1995 sampling event.

b/ Average soil concentration were calculated from analytical data collected during the 1995 sampling event.

c/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration to prevent expansion of plume boundary was estimated using analytical model ONED3 (Section 6.6.4). Used target groundwater concentration to "back calculate" groundwater protective SSTL.

d/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration = RME health-based groundwater SSTL (worker dermal exposure to groundwater) was used to "back calculate" groundwater protective SSTL.

e/ Site-specific soil leaching SSTL based on partitioning relationship developed in Section 6 to evaluate long-term leaching of soil COPC mass from soils. Based on literature-reported K_D value, site-specific foc of 0.005, and simple equilibrium partitioning model used to simulate observed site conditions. Target groundwater concentration = CT health-based groundwater SSTL (worker dermal exposure to groundwater) was used to "back calculate" groundwater protective SSTL.

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average detected soil COPC concentrations compared with generic RBSLs.) All the low-molecular-weight soil COPCs significantly exceed the soil leaching SSTLs (i.e., benzene, toluene, ethylbenzene, xylenes, and chlorobenzene). The leaching calculations presented in Section 6.6.2 demonstrate that these compounds will continue to leach from soils and have an adverse impact on underlying groundwater for about 8 to 10 more years. In contrast, the heavier hydrocarbon soil COPCs (i.e., 1,3,5-TMB and naphthalene) only slightly exceed their soil leaching SSTLs. These compounds will soon be occluded in soils, and no longer available to leach into underlying groundwater.

Table 7.4 compares the maximum detected groundwater COPC concentrations to the health-based groundwater SSTLs. Benzene, toluene, naphthalene, and 1,2,4-TMB maximum detected site groundwater concentrations exceed the health-based groundwater RME SSTLs. Benzene is the only groundwater COPC to exceed its health-based SSTL by more than an order of magnitude. All other groundwater COPCs are approaching their health-based SSTLs. In fact, it should be emphasized that toluene and naphthalene maximum concentrations are currently below the CT SSTLs and the maximum 1,2,4-TMB concentration is within an order of magnitude of both the RME and CT SSTL. The analytical model presented in Section 6.6.4 demonstrates that benzene (the indicator compound) will be reduced below its health-based SSTL by the year 2017 at every sampling location by natural chemical attenuation processes. The analytical model also projects that benzene concentrations in the plume core will be sufficiently reduced to eliminate additional plume expansion.

7.5 SUMMARY OF RISK REDUCTION REQUIREMENTS

Comparison of detected COPC concentrations to SSTLs indicate that some type of soil remediation may be necessary to achieve soil leaching SSTLs, prevent continuing adverse groundwater impacts, and minimize monitoring commitments. Natural chemical attenuation processes will minimize downgradient migration of groundwater COPCs and eventually be sufficient to reduce concentrations below the health-based SSTLs. However, the health-based groundwater SSTLs are based on dermal exposure to groundwater. Although this exposure pathway could occur under highly disruptive, intrusive activities, the probability that this exposure pathway would be complete is low. Deciding to conduct engineered remediation activities at this site on the basis of this exposure pathway would be considered a conservative risk management decision, especially considering that this exposure pathway could be easily interrupted by employing basic personal protective equipment (PPE) common to excavation work (e.g., boots, pants, long-sleeved shirts, and rubber gloves).

The presence of residual contamination at concentrations above the SCDHEC (1995) generic RBSLs and SSTLs will not interfere with the intended use of the sites nor pose a threat to human or ecological receptors. This Tier 2 evaluation demonstrates that no unacceptable risk to potential current onsite receptors exists at Site ST-27. The Air

TABLE 7.4
COMPARISON OF ANALYTICAL GROUNDWATER DATA TO SITE-SPECIFIC TARGET LEVELS
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

COPC	Units	Detected Site Maximum Concentration[a]	Tier 2 RME Health-Based SSTLs[b]	Tier 2 CT (Average) Exposure Health-Based SSTLs[c]	Tier 1 SCDHEC/EPA Generic RBSLs[d]	Does Detected Site Maximum Concentration Exceed RME SSTL?	If "YES," Does Detected Site Maximum Concentration Exceed CT SSTL?
Benzene	μg/L	6900	240[e]	640[e]	0.36	YES	YES
Ethylbenzene	μg/L	2400	2,500	3,400	700	NO	-
Toluene	μg/L	10000	8,800	12,000	750	**YES**	NO
Naphthalene	μg/L	270	260	330	25	**YES**	NO
Chlorobenzene	μg/L	41	320	430	39	NO	-
1,2,4,-Trimethylbenzene	μg/L	1400	720	950	300	YES	YES
1,3,5-Trimethylbenzene	μg/L	390	720	950	300	NO	-
cis-1,2-Dichloroethene	μg/L	26	2,000	2,600	61	NO	-

NOTE: Derivation of SSTLs presented in Appendix F.

[a] Maximum concentrations were obtained from the 1995-96 risk-based investigation sampling events.

[b] RME SSTLs are designed to protect onsite intrusive workers from unacceptable exposure due to incidental exposure via dermal contact with dissolved chemicals in groundwater using site-specific exposure assumptions (carcinogenic value for benzene; noncarcinogenic values for all other COPCs).

[c] Average or CT SSTLs (i.e., SSTLs based on average exposure assumptions) are provided for comparison with RME SSTLs for onsite intrusive workers exposed via incidental dermal contact with dissolved chemicals in groundwater (carcinogenic value for benzene; noncarcinogenic values for all other COPCs).

[d] SCDHEC (1995)/EPA Region VIII (1996) (the lesser of the two values) generic RBSLs would be protective of onsite workers whose drinking water comes from an onsite groundwater source.

[e] Health-based SSTL values for benzene (a carcinogen) are based on target risk levels of 10^{-6} (see Appendix F for calculated SSTLs values based on target risks of 10^{-4} and 10^{-5}).

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Force intends to base long-term cleanup objectives on the health-protective SSTLs, rather than pursue compliance with Tier 1 RBSLs. The Tier 2 chemical fate assessment presented in Section 6 concludes that natural chemical attenuation processes, supplemented by interim action SVE, will be sufficient to attain health-protective SSTLs in all media by the year 2017. Sections 8 and 9 describe the effectiveness of various low-cost source reduction technologies at expediting compliance with health-protective SSTLs.

7.6 SITE PRIORITY CLASSIFICATION AND TIER 2 ACTION DECISION

Based upon the Tier 2 assessment and evaluation, Site ST-27 remains classified as a Category 5 release. There is currently no demonstrable threat to potential human or ecological receptors, but data indicate that all the soil COPCs and many of the groundwater COPCs (i.e., benzene, toluene, naphthalene, and 1,2,4-TMB) are present at concentrations that exceed their respective SSTLs. However, interim action SVE and natural chemical attenuation processes will be sufficient to prevent any significant migration of contaminated groundwater.

SECTION 8

PILOT TESTING OF SOURCE-REDUCTION TECHNOLOGIES

Section 6 of this CAP shows that both destructive and nondestructive attenuation processes should be effective at minimizing contaminant migration and reducing contaminant mass over time at Site ST-27. To date, two source reduction technologies have been evaluated at Site ST-27 in the event that engineered source reduction is required to protect human and/or ecological receptors or to reduce the total time and cost of remediation. *In situ* bioventing and SVE pilot tests were completed at the site to determine the effectiveness of these remedial techniques on treating site-related contamination. Parsons ES conducted a bioventing pilot test at Site ST-27 in May 1993 as part of a separate AFCEE remedial technology testing program. Detailed results of initial bioventing pilot testing at Site ST-27 are presented in the *Interim Bioventing Pilot Test Results Letter Report for IRP Site ST-27, Charleston AFB, South Carolina* (ES, 1993). Early in 1996, SVE pilot testing was implemented at this site by Parsons ES as part of the risk-based site investigation. Results from the initial bioventing pilot test and the SVE pilot test at Site ST-27 are summarized in this section. Test data are presented in tabular form in Appendix G.

8.1 *IN SITU* BIOVENTING PILOT TESTING

8.1.1 Bioventing Well and Vapor Monitoring Point Installation

A vertical air injection VW (VW-1) and three VMPs (MPA, MPB, and MPC) were installed by ES in May 1993 (Figure 8.1). One 2-inch-diameter PVC VW was installed in contaminated source area soils. VW-1 is screened from approximately 3 to 10 feet bgs. Groundwater was encountered in the VW borehole at approximately 5 feet bgs during VW installation.

The three soil VMPs are screened in the unsaturated zone with 6-inch-long sections of 0.5-inch-diameter well screen centered at depths of approximately 3.0 to 3.5 feet bgs. Thermocouples were installed at MPA and MPC to measure soil temperatures.

8.1.2 Respiration Testing

In situ respiration testing was performed at Site ST-27 to determine oxygen utilization rates and potential biodegradation rates. Testing was performed by injecting a mixture of air (oxygen) and approximately 4.5-percent helium (inert tracer gas) into the three screened VMP intervals (MPA-3.5, MPB-3.5, and MPC-3.5) for a 17.5-hour

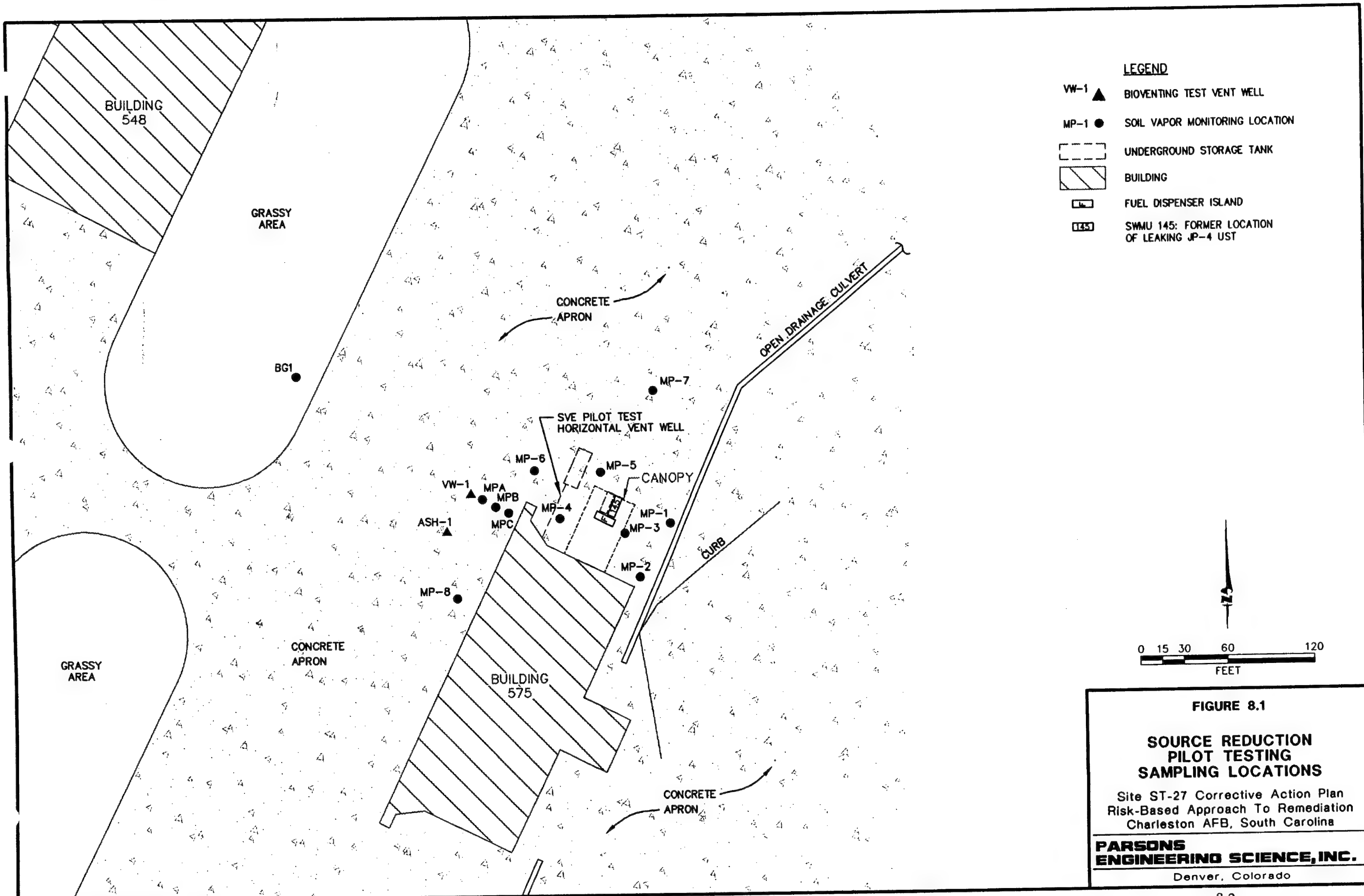

FIGURE 8.1

SOURCE REDUCTION PILOT TESTING SAMPLING LOCATIONS

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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period. Oxygen, TVH, carbon dioxide, and helium were then measured for a period of approximately 28 hours following air injection. The measured oxygen losses were used to calculate biological oxygen utilization rates.

Because helium is a conservative, inert gas, the changes in helium concentrations over time can be useful in determining the effectiveness of the bentonite seals above the screened intervals. Because the observed helium loss was negligible at Site ST-27, and because helium will diffuse approximately three times faster than oxygen due to oxygen's greater molecular weight, the measured oxygen loss at the site was the result of bacterial respiration and not due to faulty monitoring point construction. The soil gas oxygen concentration at the uncontaminated background VMP was 19.5%, indicating that abiotic or nonfuel biological oxygen uptake is negligible in shallow soils at this site.

Oxygen loss occurred at moderate rates, ranging from 0.388 percent per hour at the VW to 0.491 percent per hour at MPC-3.5. At MPC-3.5, the oxygen dropped from 20.0 percent to 7.0 percent in 1,530 minutes, or approximately 1.1 days. Oxygen utilization rates are summarized in Table 8.1.

TABLE 8.1
OXYGEN UTILIZATION RATES DURING INITIAL BIOVENTING PILOT TESTING
SITE ST-27, CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Location	O_2 Loss[a/] (%)	Test Duration[b/] (minutes)	O_2 Utilization Rate (%/hour)
MPA-3.5	12.1	1,740	0.424
MPB-3.5	11.6	1,740	0.401
MPC-3.5	14.1	1,740	0.491

[a/] Actual measured oxygen loss.
[b/] Elapsed time from beginning of test to time when minimum oxygen concentration was measured.

Based on these oxygen utilization rates, an estimated 160 to 1,150 mg of fuel per kg of soil can be degraded each year at this site. This estimate is based on a ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded (ES, 1993). Actual degradation rates may initially exceed these estimates, then may decrease as readily degradable constituents (such as BTEX) are removed, leaving more biologically recalcitrant compounds to degrade more slowly.

8.1.3 Air Permeability Testing

During the initial bioventing investigation, an air permeability test also was conducted at Site ST-27. Air was injected into the VW for 142 minutes at a rate of approximately 3.7 standard cubic feet per minute (scfm). Using the HyperVentilate® model for determining air permeability, an average soil gas permeability value of 4.4

darcys were calculated for this site. A radius of pressure influence of at least 30 feet from the VW was observed at the 3.5-foot depth (ES, 1993). Test data and associated calculations are presented in Appendix G.

The radius of oxygen influence in the subsurface resulting from air injection into the VW during pilot testing is the primary design parameter for full-scale bioventing systems. Optimization of full-scale, multiple VW systems requires pilot testing to determine the volume of soil that can be oxygenated at a given flow rate and VW screen configuration. The duration of the air permeability test was limited to approximately 2 hours to minimize the migration of contaminated soil gas away from the VW or into any subsurface feature (e.g., utility corridors or the foundation of Building 575). This short-duration air injection test produced changes in soil gas oxygen levels at MPA and MPB (Figure 8.1). Changes in soil gas oxygen levels were not observed at MPC during the limited test, but this most likely was due to the limited injection time. A more accurate indication of oxygen radius of influence was obtained during the extended SVE pilot test (Section 8.2).

8.1.4 Bioventing Test Results

Initial pilot testing indicated that bioventing would be effective in remediating petroleum hydrocarbon contamination in shallow, unsaturated soils at Site ST-27. Additionally, a recent pilot test at Site SS-41 on Charleston AFB indicated bioventing is highly effective in reducing BTEX contamination in unsaturated soils underlying Charleston AFB. Results of the 1-year pilot test performed at Site SS-41 demonstrated a 99 percent reduction in soil BTEX concentrations. However, due to elevated concentrations of volatile hydrocarbon vapors in unsaturated soils underlying Site ST-27, and the potential for vapor migration into Building 575, extended air injection was not performed at Site ST-27. Sections 6 and 7 demonstrated that the pre-SVE pilot test soil gas levels did not pose a health threat under natural diffusion/convective processes. However, the measured concentrations exceeded the LELs for gasoline, which could pose an explosive hazard if vapors were to accumulate in a confined space. Consequently, SVE is recommended for implementation as an interim action at the site to remove the majority of the volatile hydrocarbons vapors from unsaturated and capillary fringe soils. Bioventing could then be implemented at the site once initial SVE operations have reduced concentrations of volatile hydrocarbons in soil gas to well below the LELs (<10,000 ppmv). Indoor air monitoring would be conducted in Building 575 during bioventing system startup to verify that elevated concentrations of vapors are not migrating into the building. It is expected that SVE operations will reduce shallow soil hydrocarbon vapor concentrations to well below the LELs within approximately 3 to 6 months within the zone of influence of the SVE vent well(s).

8.2 SVE PILOT TESTING

SVE was evaluated as a potential remedial technology for the treatment of volatile hydrocarbon vapors in the unsaturated zone at Site ST-27. Extracting vapor from contaminated soils serves two purposes: 1) volatilizing compounds with high vapor pressures from unsaturated soils, and 2) supplying oxygen to soils to enhance biodegradation of less volatile compounds. As contaminated soil gas is extracted from the site source area, oxygen-rich soil gas is drawn into the source area soils from surrounding uncontaminated soils.

The radius of vacuum and oxygen influence resulting from vapor extraction and the hydrocarbon recovery rate are the primary design parameters for full-scale SVE systems. Optimization of full-scale, multiple well systems requires pilot testing to determine the radius of influence that can be treated at a given flow rate and vacuum. The following subsections summarize the SVE test procedures and results, and assess the applicability of this technology for source reduction at Site ST-27.

8.2.1 SVE Well and Monitoring Point Installation

A 4-inch-diameter PVC horizontal venting well (HVW) was installed at Site ST-27 in January 1996. The HVW was placed approximately 3 feet bgs in a 40-foot-long trench at the northwestern corner of Building 575 (Figure 8.1). The HVW was constructed with 30 feet of 0.020-inch-slotted PVC screen exposed to contaminated soils. In June of 1996, a second HVW was completed approximately 50 feet east of the original HVW. This HVW was constructed with 40 feet of 0.02-inch-slotted, 4-inch PVC. The purpose of the second HVW was to expand the radius of influence to contaminated soils on the eastern half of the site. HVW construction diagrams are included in Appendix B. The VMPs installed during the 1993 Bioventing Test (MPA, MPB, and MPC) and during the 1995 risk-based field effort (MP-1 through MP-8) provide soil gas chemistry data from sample points located throughout unsaturated source area soils during SVE pilot testing.

8.2.2 SVE Pilot Testing Procedures

An initial SVE pilot test was performed at Site ST-27 from February 8 through April 19, 1996 to determine the feasibility of reducing fuel vapor contamination within shallow source area soils. Initial soil gas oxygen, carbon dioxide, and TVH concentrations were measured at monitoring points MP-1 through MP-8, MPA, MPB, and MPC prior to extracting soil vapor from the HVW. (Table 8.2). Following initial soil gas measurements, vapors were extracted from the HVW over 64 days of operation. Extracted vapors were treated with a VR Systems® model V2C internal combustion engine (ICE). This treatment system uses a modified automobile engine to extract and combust volatile hydrocarbon vapors. Manufacturer's information on the ICE is presented in Appendix G.

Extraction rates and pressures were varied throughout the operation period to prevent mounding and extraction of shallow groundwater at the HVW and to minimize ICE operating costs. Air extraction rates varied from 7 to 47 scfm, with an average rate of approximately 21 scfm and an average extraction vacuum of approximately 33 inches of water (Table 8.3). Throughout system operation, extracted soil gas concentrations, extraction vacuum, and flow rate were periodically measured and recorded at the influent and effluent of the ICE via automated instrumentation and manual methods. Based on the average extracted soil gas TVH concentration and flow

TABLE 8.2
IMPACT OF SVE PILOT TEST ON SOIL GAS CHEMISTRY
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Vapor Monitoring Point	Distance From HVW (feet)	Initial Values (2/7/96) TVH (ppmv) [a]	Initial Values (2/7/96) Oxygen (%)	Initial Values (2/7/96) Carbon Dioxide (%)	Initial Values (2/7/96) Vacuum (inches water)	Day 34 of Testing (3/12/96) TVH (ppmv)	Day 34 of Testing (3/12/96) Oxygen (%)	Day 34 of Testing (3/12/96) Carbon Dioxide (%)	Day 34 of Testing (3/12/96) Vacuum (inches water)
MP-1	85	>20,000 [b]	3.7	3	0	5,000	8.5	4.8	0.1
MP-2	65	>20,000 [b]	1.8	3.9	0	10,000	10.4	4.1	0.2
MP-3	50	66,000	0	8	0	5,000	0	8.8	0.1
MP-4	10	200,000	0	5.5	0	6,200	15.5	3.9	5.5
MP-5	45	110,000	0	4.5	0	5,200	2.2	8.9	0.3
MP-6	25	>20,000 [b]	0.6	4.3	0	18,400	2.2	6.0	3.9
MP-7	115	>20,000 [b]	0.6	4.3	0	1,480	0	7.2	0
MP-8	75	>20,000 [b]	0	5.9	0	6,800	0.2	6.9	0
MPA	40	120,000 [c]	0 [c]	6.9 [c]	0	8,600	1.8	6.5	0.5
MPB	30	>20,000 [b]	0 [c]	NA [d]	0	11,800	1.8	6.7	0.6
MPC	20	75,000 [c]	0	6.0	0	10,200	1.1	6.8	0.9

[a] TVH = Total volatile hydrocarbons; ppmv = parts per million volume per volume.
[b] TVH concentrations above calibration limit of field instrument (Gas Tech TraceTechtor™).
[c] Based on ES (1993) bioventing pilot test analytical results.
[d] NA = Not available.

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TABLE 8.3
INTERNAL COMBUSTION ENGINE/SVE PERFORMANCE
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Parameter	Date								Average
	2/8/96	2/15/96	2/21/96	2/26/96	3/12/96	3/18/96	4/1/96	4/19/96	
Flow Rate (scfm)[a/]	47	13	17	24	26	14	NA[b/]	7	21
Vacuum (inches water)	35	35	36	36	35	39	NA	14	33
Influent Soil Gas TVH (ppmv)[c/]	2,840	2,900	4,700	860	2,500	6,100	3,500	3,900	3,412
Influent Benzene (ppmv)	40	40	58	17	37	97	36	44	46
ICE Effluent TVH (ppmv)	34	26	49	10	38	700	180	8.4	131
TVH Destruction Efficiencey (%)	98.8	99.1	99	98.8	98.5	88.5	94.8	99.8	97.1
Propane Consumption (scfm)	0.2	0.8	0.6	0.9	0.6	0.7	NA	0.6	0.6

[a/] scfm = Standard cubic feet per minute.

[b/] NA = Not available.

[c/] TVH = Total volatile hydrocarbons; ppmv = parts per million volume per volume.

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rate, an estimated 1,875 pounds of VOCs, including 19 pounds of benzene, were removed during the initial 64-day pilot test. The ICE provided an average VOC destruction efficiency of 97.1 percent.

Two observations can be made with respect to the SVE pilot test. The first observation is that the extracted TVH concentrations were relatively stable over time (Table 8.3), which is unusual for SVE systems. These data suggest that there was a stable source of VOC in the source area. Leak testing conducted on the active fuel tanks and pipelines at Building 575 indicated that a fuel transfer pipe located within 20 feet of the HVW may have had a small but continuous leak throughout the SVE pilot test period. This pipeline, which was removed from service following the SVE pilot test, was the likely fuel source that generated these VOCs. The second observation was that short-circuiting was occurring in the vicinity of the UST vaults approximately 15 feet from HVW #1 and possibly through expansion joints or other cracks in the concrete (Figure 8.1). This short-circuiting noticeably affected the efficiency of soil gas (and VOC) extraction in the vicinity of MP-3.

8.2.3 SVE Pilot Testing Results

8.2.3.1 Radius of Influence

Changes in vacuum influence and soil gas chemistry were used to determine the effective radius of influence of the single HVW (Table 8.2). Vacuum response was measured at the monitoring points to determine the maximum radius of potential soil gas exchange which is an approximate measure of the treatment radius of influence of the HVW. A vacuum response equal to or greater than 0.1 inch of water was measured as far away as 85 feet at MP-1. However, the radius of vacuum influence was not uniform in all directions due to interrupted flow paths caused by buried tanks and pipelines. Significant increases in oxygen concentrations also were observed up to 85 feet from the HVW at MP-1 (Table 8.2). The maximum oxygen increase was measured at MP-4, located 10 feet from the HVW (Figure 8.1). With the exception of MP-3, all VMPs within a 50- foot radius of the HVW exhibited significant increases in oxygen as a result of the first 34 days of SVE operations. Significant decreases in TVH concentrations also occurred at all VMPs as the hydrocarbon vapors were removed from the center of the spill site and replaced with uncontaminated soil gas. These data indicate that SVE is an effective technology for reducing volatile hydrocarbon (specifically BTEX) concentrations and increasing oxygen in contaminated soil gas in a conservative radius of influence of 50 feet from the extraction well. However, pilot testing also indicated that an additional HVW would be required to effectively treat contaminated soils in the vicinity of MP-3. It appears that some short-circuiting is occurring between the HVW and MP-3 as a result of the tanks and pipelines in this area. An additional HVW has been constructed (see Figure 9.1) to complete SVE pilot testing and to ensure that all soil contaminant source areas at the site can be treated using SVE and bioventing.

8.2.3.2 Potential VOC Emissions

The long-term potential for significant emissions of VOCs into the atmosphere from full-scale SVE operations at this site is low. Emissions would be minimal because of the proven efficiency of VR Systems' ICE treatment technology (typically 97-99

percent destruction of VOCs). Air sampling conducted during system startup verified that the system was operating with a 97-percent average VOC destruction efficiency. ICE effluent vapor samples collected throughout the startup and operation of the SVE test indicate that emissions from the ICE were at least two orders of magnitude below SCDHEC RBSLs (Table 8.3).

8.3 POTENTIAL PILOT TEST ACTIVITIES

One additional remedial technology was considered as a potential source reduction technology for Site ST-27. Biosparging could be used to enhance treatment of shallow dissolved groundwater contamination and residual capillary fringe contamination should it be necessary to accelerate the remediation time-frame or attain additional risk reduction at this site. Before biosparging could be implemented, additional pilot-scale testing would need to be performed to evaluated the combined effects of biosparging and SVE prior to full-scale, source-reduction system design. A biosparging pilot test would be conducted using a 20-foot section of horizontal sparge well located near one of the horizontal SVE/bioventing wells. Soil gas concentrations and DO would be monitored at the points during pilot testing to assess the ability of the system to introduce DO into groundwater, to volatilize dissolved contaminants from groundwater and saturated soils, and to supply oxygen to the capillary fringe and vadose zone. SVE would be conducted in conjunction with biosparging pilot testing to prevent migration of elevated concentrations of fuel hydrocarbon vapors into subsurface utilities or nearby buildings.

SECTION 9

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Sections 6 and 8 provide scientific documentation of natural attenuation processes and the potential benefits of SVE, bioventing, and biosparging in accelerating the remediation of the source area at Site ST-27. An initial screening of remedial approaches and technologies was completed, and several technologies were identified for possible use at Site ST-27. A complete review of the initial screening process is included in Appendix H. Three remedial alternatives were developed using various combinations of public education, land and groundwater use controls, long-term monitoring (LTM), natural attenuation, SVE, *in situ* bioventing, and biosparging. The objectives of Section 9 are to summarize the alternatives developed from the technologies screened in Appendix H, to review the primary evaluation criteria used to compare these alternatives, and to complete a more detailed comparative analysis of each alternative in an effort to identify the most logical approach for remediating Site ST-27. Each alternative is more fully explained in terms of its effectiveness, technical and administrative implementability, and cost. Following this evaluation, an implementation plan and LTMP for the recommended alternative are summarized in Section 10.

9.1 SUMMARY OF CANDIDATE REMEDIAL ALTERNATIVES

Based on the initial remedial screening process, which is summarized in Appendix H, several remedial approaches and technologies were retained for the development of remedial alternatives. These technologies were selected to provide a range of passive to more active response actions, all of which will minimize contaminant migration, minimize increases in contaminant concentrations, and prevent receptor exposures. The primary goal of all the candidate alternatives is to remediate Site ST-27 to a point at which no contaminant concentrations exceed Tier 2 SSTLs. The SSTLs for Site ST-27 would be met in slightly different time frames and at different costs under each alternative. The following remedial approaches and technologies were retained for evaluation:

- Long-term soil gas and groundwater monitoring;
- Limited land use controls;
- Groundwater use controls;
- Public education;
- Natural attenuation of soil and groundwater contamination;

- Biosparging in the source area;
- SVE in the source area; and
- Post-SVE bioventing for the treatment of residual soil contamination.

The primary objective of source reduction technologies would be to more rapidly remove contaminants from the shallow groundwater and unsaturated soils near Building 575, the suspected source area at Site ST-27. Accelerating the reduction of source contamination will result in a decrease in the length of time that will be required to attain the appropriate SSTLs for Site ST-27. Additionally, interim source reduction actions (i.e., SVE), which have been implemented to reduce potential explosive and outdoor inhalation hazards, may allow implementation of more cost-effective approaches. As discussed in Sections 4 and 7, soil gas concentrations at the site currently exceed BTEX PELs and the MOGAS LEL. The conservative volatilization model indicates that ambient outdoor air concentrations in and around Building 575 could exceed Tier 2 SSTLs for some VOCs if the concrete apron is removed (Section 6). An SVE system has been installed at the site and is currently operating as an interim action to remediate the elevated soil gas concentrations to levels that are well below LELs for MOGAS and below the levels that could result in exceedances of the toluene, ethylbenzene, and xylene PELs in ambient air if the concrete apron is disturbed or removed.

The maximum concentrations of most contaminants in groundwater and vadose zone soils have been detected around the USTs north of Building 575. The exception is cis-1,2-DCE, which was detected at its maximum concentration to the east of Building 575, adjacent to the aircraft wash rack. Results from the 1995 soil sampling event in the source areas indicate that the soil contaminant mass and concentrations are below health-based RBSLs appropriate for an industrial/construction land use. However, soil contaminant concentrations were measured in excess of SSTLs (and RBSLs) that are protective of groundwater underlying the source area. Additionally, limited LNAPL in the vicinity of groundwater monitoring wells MW20-1 and MW20-5 could continue to be a source of contamination for groundwater at and downgradient from Site ST-27 (Section 6).

Because natural attenuation has been effectively reducing dissolved contaminants in the groundwater and limiting downgradient migration (Section 6), this ongoing remediation process can best be enhanced through a reduction of the continuing source of contamination at Site ST-27. Two candidate source soil reduction technologies (interim SVE for the treatment of contaminated soil gas and *in situ* bioventing for the treatment of residual soil contamination) and one *in situ* groundwater treatment technology (biosparging) have been retained for additional analysis. Three candidate remedial alternatives were developed and are described in the following sections.

9.1.1 Alternative 1 - SVE as an Interim Action, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 1: Attainment of the most restrictive Tier 2 SSTLs by the year 2017.

Section 6 presents evidence that groundwater contaminants are being remediated by natural physical, chemical, and biological processes. Soil gas sampling performed during the 1995 risk-based investigation indicated that soil gas concentrations in shallow, unsaturated soils at Site ST-27 exceed the OSHA BTEX PELs and the MOGAS LEL. A quantitative exposure pathway analysis showed that vapors theoretically could migrate into the ambient atmosphere at concentrations that could pose an unacceptable risk to potential receptors if the concrete apron is removed. A pilot-scale SVE test was performed by Parsons ES at Site ST-27 in the spring of 1996. The detailed results of this test are presented in Section 9.2. As the test results indicate, SVE can effectively remove contaminated soil vapors and VOCs from unsaturated soils and LNAPL at Site ST-27. One 4-inch-diameter, 40-foot-long HVW was installed at part of the SVE pilot test. An additional HVW was installed in June 1996 as part of the interim action at the site. This extraction well was connected to the VR Systems ICE currently operating at the site. Figure 9.1 presents the location of the existing HVWs that would be used for full-scale SVE at Site ST-27 as part of this corrective action approach. SVE was implemented at the site as an interim action to mitigate potential unacceptable hazards. This full-scale system will continue to operate at the site until soil gas TVH levels in the vicinity of Building 575 have been reduced to an equilibrium concentration of about 5,000 ppmv, which is well below the LEL of 10,000 ppmv for MOGAS. This mass reduction should be more than adequate to prevent exceedance of ambient air PELs for VOCs at all VMP sampling locations at Site ST-27.

On the basis of 1995 soil sampling results presented in this CAP, soil COPC concentrations exceed the soil leaching SSTLs and RBSLs that are protective of underlying groundwater. Increases in dissolved contaminant concentrations and some plume expansion could occur. It is important to note that health-based RBSLs for soil were not exceeded in any sample collected at the site. This means that soils pose no health risk to onsite workers. Soil remediation would only be warranted to prevent continuing degradation of onsite groundwater, which is not and will not be used as a potable water source.

Although LNAPL is not separately removed under this alternative, the small quantity of product known to be present at the site will not pose a risk to potential downgradient receptors due to the lack of significant plume migration projected to occur at the site. Weathering calculations outlined in Section 6.6.3 indicate that COPCs will gradually partition from the free-phase product into the groundwater for the next 10 to 12 years. The weathering process (removal of BTEX) is expected to be enhanced by the initial SVE operations at the site.

Section 6 provides a thorough evaluation of natural attenuation processes operating at the site, and of the analytical model that was used to simulate the effects of these

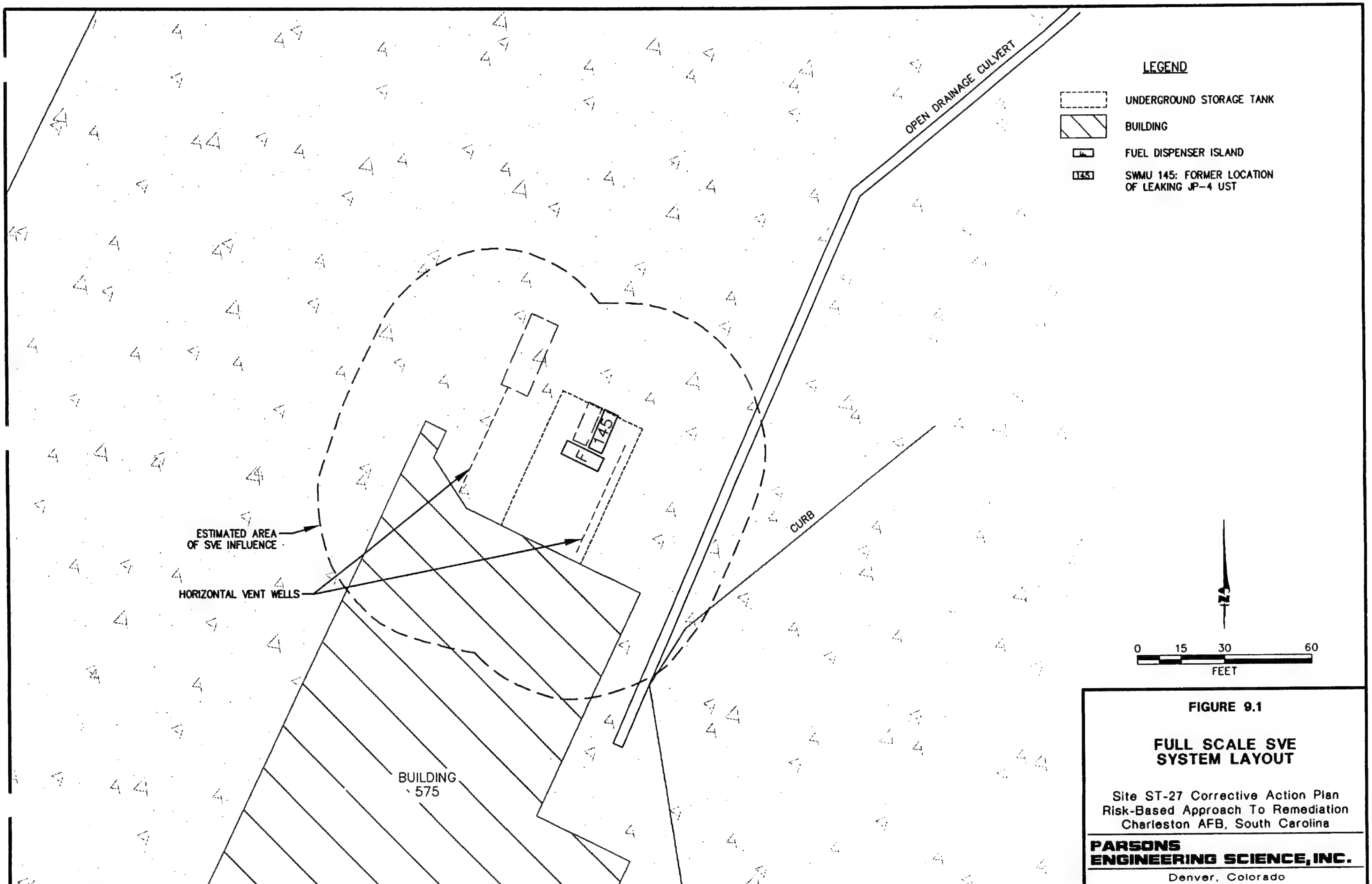

FIGURE 9.1

FULL SCALE SVE SYSTEM LAYOUT

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
Charleston AFB, South Carolina

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processes on contaminant mass and mobility over time. The model for this alternative predicted that the existing plume should stabilize by the year 2003. By the year 2017, groundwater COPCs will be reduced below the Tier 2 SSTLs that protect onsite workers should this receptor group ever be incidentally exposed to contaminated onsite groundwater. The model also suggests that the plume will not migrate significantly further downgradient than it would if the small quantity of remaining LNAPL were to be actively removed. Groundwater use restrictions would be instituted until all groundwater impacted by Site ST-27 meets appropriate RBSLs. Limitations on groundwater use would not pose additional restrictions on current or planned future land use in this uninhabited industrial area.

This alternative would include semi-annual monitoring of groundwater for the first 2 years and annual monitoring thereafter to verify and document that SVE and natural attenuation are minimizing contaminant mass and mobility. Natural processes have been removing and should continue to remove contaminant mass and limit contaminant migration. The progress of intrinsic remediation would be monitored using the existing network of monitoring wells. POA wells would be used to ensure that no contaminant concentrations above groundwater RBSLs migrate beyond the area of established exposure controls (i.e., an area of restricted groundwater use would be identified). Additional details on the frequency and types of groundwater analyses recommended to confirm natural attenuation are presented in the LTMP included in Section 10.

9.1.2 Alternative 2 - SVE as an Interim Action, Continuing *In Situ* Bioventing in Source Area, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 2 - Attainment of the most restrictive Tier 2 SSTLs by the year 2007.

Alternative 2 is similar to Alternative 1 except that *in situ* bioventing would be used to treat residual soil and LNAPL contamination after interim SVE has lowered soil gas TVH concentrations to an equilibrium concentration of about 5,000 ppmv. After this equilibrium soil gas concentration is attained, the existing SVE wells would be reconfigured for the injection of air (oxygen) to promote biodegradation of the remaining vadose zone contamination at Site ST-27. The SVE system currently in operation at the site has already removed more than 3,000 pounds of fuel residuals in the source area through volatilization. Long-term bioventing would be used to remediate residual BTEX occluded in the "smear zone" after SVE has reduced soil gas contaminant levels. It is anticipated that the SVE system at Site ST-27 would be in operation for 3 to 6 months to reduce equilibrium soil gas contaminant concentrations to half the LEL for MOGAS and to also attain ambient PELs. After operation of the SVE system, it is anticipated that 1 to 2 years of bioventing would be required to reduce soil contaminant concentrations to levels below the Tier 2 SSTLs that protect underlying groundwater.

The analytical model presented in Section 6 also was used to simulate the positive effects of SVE and bioventing in the source area (details are presented in Appendix E). The anticipated impact of SVE and bioventing on reducing contaminant loading to groundwater from contaminated soils was incorporated into the analytical model by reducing the source term over time. This approach assumes that 99 percent of the

BTEX residuals in the soil will be removed by bioventing after 2 years. The ability of bioventing to remove BTEX compounds was recently demonstrated at Site SS-41 on Charleston AFB. During a 1-year bioventing pilot test at this site, soil BTEX concentrations were reduced by over 99 percent (ES, 1993b). In the analytical model, the remaining mass of COPCs was assumed to be available to slowly partition from the residual LNAPL and dissolve into underlying groundwater. Details on these source term calculations are presented in Section 6.6 and Appendix E. Figure 9.2 presents the projected impact of SVE, bioventing, and natural weathering on the dissolved plume and the extent of migration over time. Removal of the small quantities of remaining LNAPL will occur during the dry season each year when fuel residuals are smeared through the vadose zone and are available for oxygen enhanced biodegradation.

The analytical model for this alternative predicts that after 5 years the maximum dissolved concentration of benzene would be 46 percent less than if no SVE/bioventing activity is initiated (i.e., 3,940 µg/L compared to more than 7,300 µg/L). The total mass of COPCs in the groundwater would be approximately one-half the mass anticipated if no source reduction was implemented at the site. However, the effects of the source reduction technologies would not appreciably outpace the effects of natural source weathering and natural contaminant attenuation processes over time. Hence, if source reduction is implemented, the dissolved contaminant plume would stabilize and start to decrease in size after approximately 2 to 3 years. Site ST-27 would meet the most restrictive Tier 2 SSTLs in about 11 years (i.e., 2007) under this alternative.

Land use and groundwater use controls for Alternative 2 would be identical to those described for Alternative 1. Additional site access would be required to maintain the SVE and bioventing systems. Long-term groundwater monitoring also would be the same as Alternative 1. Additional soil gas monitoring and effluent testing also would be required for the full-scale SVE and bioventing systems to document the amount of contaminant mass being removed from the vadose zone and to ensure optimal system performance.

9.1.3 Alternative 3 - SVE as an Interim Action, *In Situ* Biosparging in Source Area, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 3 - Attainment of the most restrictive Tier 2 SSTLs by the year 2006.

Remedial alternatives 1 and 2 were developed to show that natural chemical attenuation mechanisms, low-cost source reduction technologies, exposure controls, and rational risk management decisions would be sufficient to protect human health and the environment at Site ST-27. Conservative modeling results suggest, however, that additional downgradient plume migration is anticipated before complete stabilization and eventual destruction is achieved. To retard additional plume migration to the extent possible at this site, it would be necessary to implement much more aggressive remedial technologies. Additionally, contaminant concentrations would persist in onsite groundwater at levels that are above the health-based SSTLs for incidental

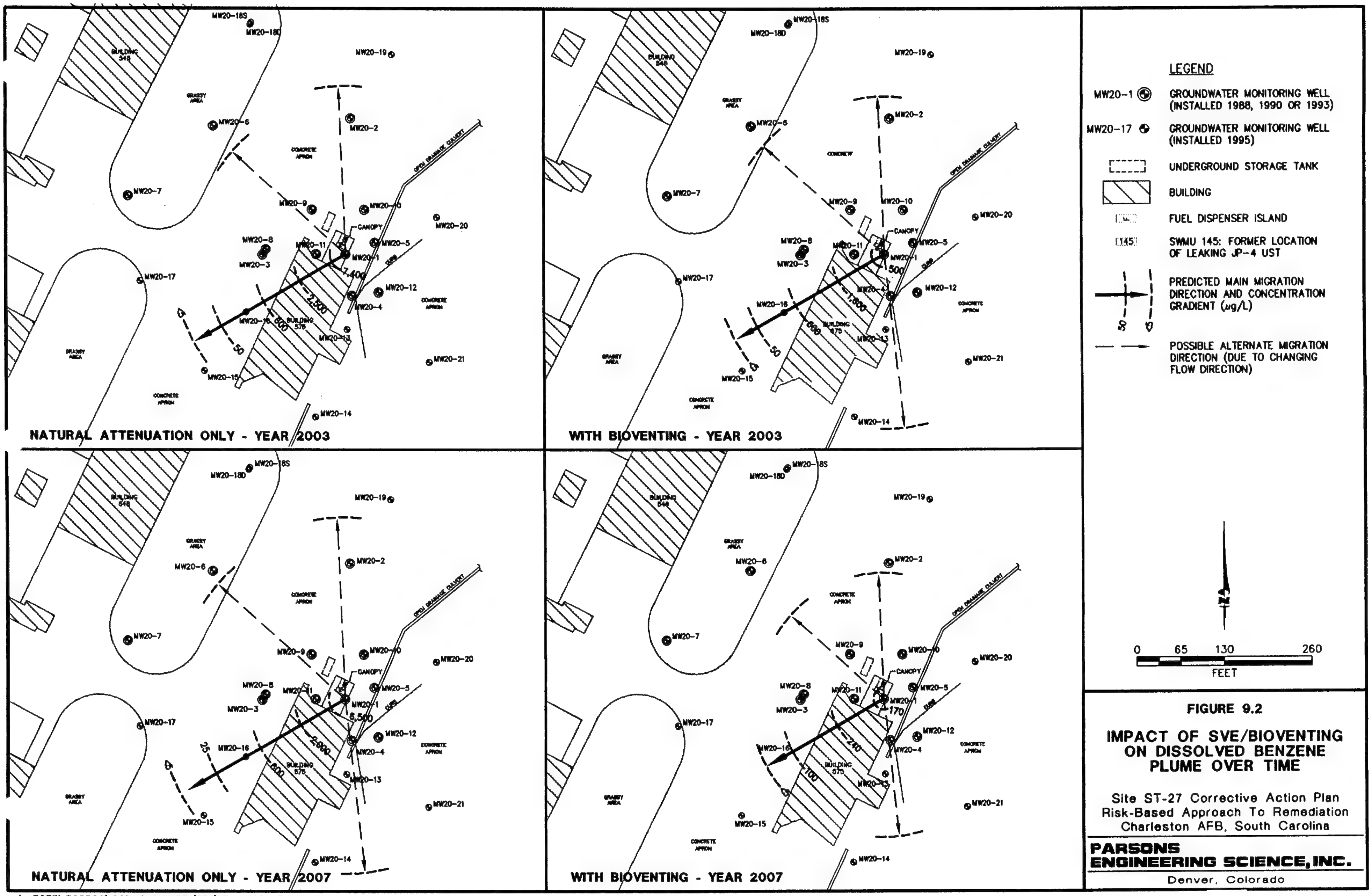

FIGURE 9.2

IMPACT OF SVE/BIOVENTING ON DISSOLVED BENZENE PLUME OVER TIME

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Risk-Based Approach To Remediation
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contact for an extended period of time under the first two alternatives. Biosparging could be implemented at Site ST-27 to more rapidly reduce groundwater contamination to levels which no longer pose a human health risk, even under conservative exposure assumptions. Alternative 3 combines groundwater treatment through biosparging with the SVE system described in the first two alternatives. Air injection bioventing would not be performed as part of Alternative 3 because the SVE system may be required during the initial months of operation to collect vapors generated by the injection of air into shallow groundwater at the site. Under this alternative, a biosparging system would be installed in the source area to volatilize dissolved VOCs and oxygenate groundwater to promote biodegradation of the less volatile contaminants. The biosparging system would be coupled with the SVE system at the site to ensure that any hazardous vapors generated by air injection into the subsurface are collected and treated. The combination of sparging and SVE would also supply oxygen to the unsaturated soils to promote bioventing. The proposed locations of the sparging wells and the SVE system is shown on Figure 9.3. Natural attenuation would continue to be the primary removal mechanism for the small mass of contaminants that has already migrated beyond the biosparging area of influence (Figure 5.5).

Based on biosparging pilot tests conducted at sites with conditions similar to those at Site ST-27, a sparging radius of influence of approximately 7 to 10 feet per well is anticipated (Acomb *et al.*, 1995). Based on a radius of influence of 10 feet, approximately six lines of horizontal air injection wells would be required to treat the source area at Site ST-27. The two-trench SVE system proposed in Alternatives 1 and 2 will be adequate to capture vapors created as a result of biosparging. To fully determine all design variables, a biosparging pilot test would be performed at Site ST-27 using a single horizontal air injection well. Full-scale system installation would involve horizontal drilling and installation of the air sparging wells, and the installation of air supply lines and a large, positive-displacement blower. Groundwater and soil gas sampling would be performed at groundwater monitoring wells within and adjacent to the treatment area to monitor system performance. Groundwater would be sampled for COPC concentrations and DO levels. A conservative tracer such as helium also could be introduced into the sparging air to determine radius of influence and air recovery efficiency. Soil gas also would be sampled for volatile COPC concentrations to attempt to quantify the amount of contaminants being removed from groundwater. SVE system influent and effluent sampling would be performed to monitor vapor capture and treatment efficiencies. Finally, health and safety monitoring would be performed in and around Building 575 to ensure that hazardous vapors are not being forced into the building or ambient atmosphere. Preliminary estimates, engineering assumptions, and calculations for the sizing and design of the biosparging system (Figure 9.3) are presented in Appendix H.

The analytical model presented in Section 6 also was used to simulate the effects of sparging the source area. In summary, the biosparging system was assumed to supply an additional approximately 1 mg/L of DO to the source area groundwater. The increase in DO would cause an increase in the expressed assimilative capacity of the source area groundwater (Table 6.3). By increasing the concentration of DO in the source area, the degradation rate in this area also would increase. The analytical model was constructed so that the area within the radius of influence of the proposed biosparging system was subject to additional degradation as a result of the additional

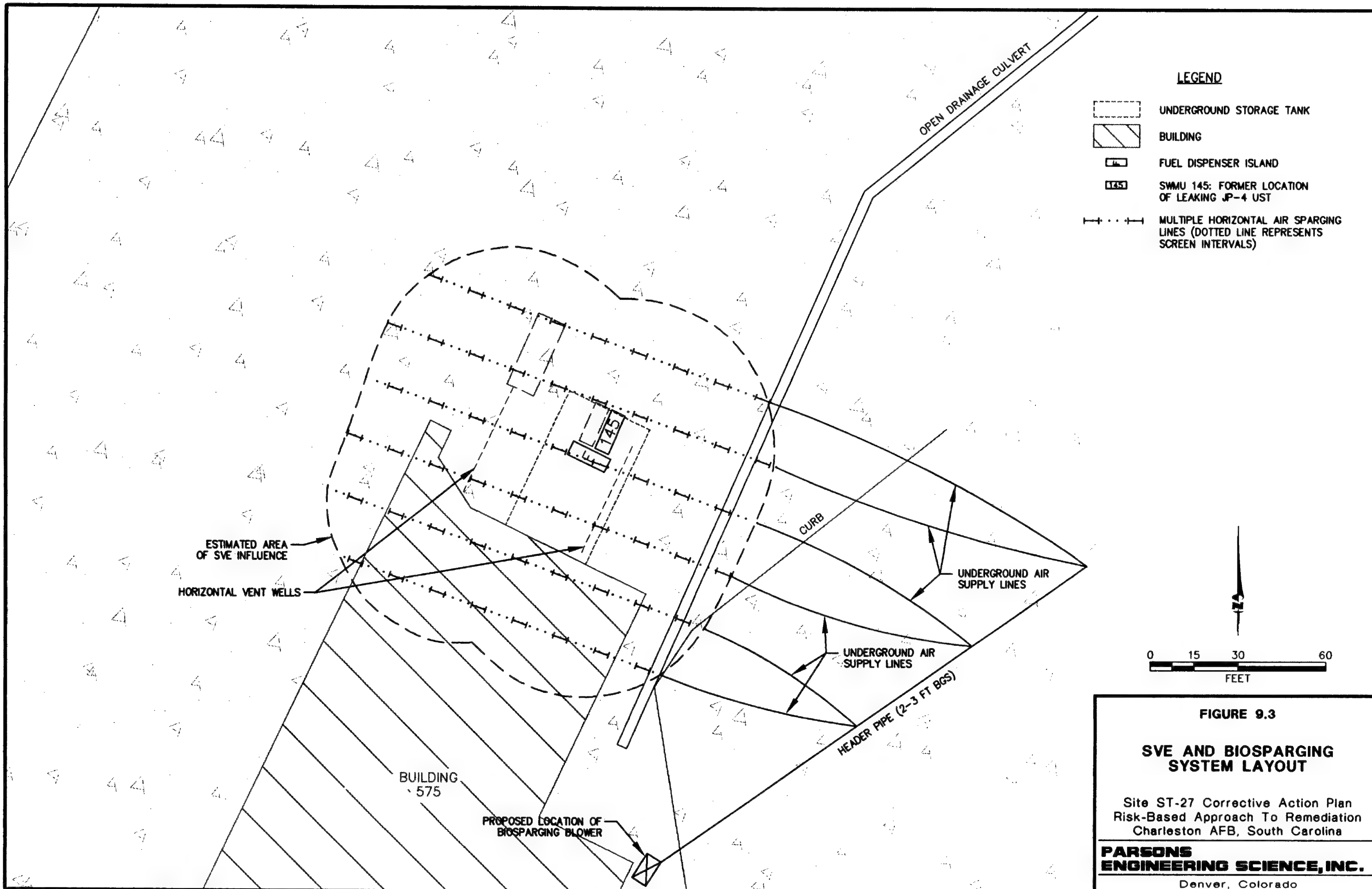

FIGURE 9.3

SVE AND BIOSPARGING SYSTEM LAYOUT

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
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0.321 mg/L of fuel hydrocarbon assimilative capacity (i.e., 1 mg/L DO can be used to facilitate the degradation of 0.321 mg/L of fuel COPCs). For example, by introducing 1 mg/L of DO into the source area groundwater and decreasing the soil source by SVE, the half-life of benzene within the radius of influence of the sparging system decreased from 4.9 years to about 2.4 years. Details on model setup and assumptions are presented in Appendix E.

The analytical model for this alternative predicted that the maximum concentrations of dissolved benzene can be effectively reduced by more than 50 percent within 1 to 2 years of full-scale system operation. Contaminant concentrations are expected to be reduced below the health-based Tier 2 SSTLs within the source area by the year 2000, but dissolved contamination beyond the area of effective sparging treatment will not be uniformly reduced to these levels until the year 2006. Only limited downgradient plume migration is expected. Land and groundwater use controls similar to those described for Alternative 1 would be implemented until groundwater contaminants are reduced to concentrations below the most stringent Tier 2 SSTLs at all points in the impacted area. During groundwater treatment, long-term groundwater monitoring would continue as detailed for Alternative 1.

It is anticipated that this alternative for groundwater treatment and source reduction could achieve the most restrictive SSTLs in all affected media within 10 years (i.e., 2006). It is anticipated that at least 12 months would be required to perform all of the pilot testing, contracting, permitting, and construction required for the installation of the SVE and biosparging systems. For costing purposes, it was assumed that the SVE system would operate in conjunction with the biosparging system for 3 years to achieve the most restrictive SSTLs within the effective treatment area at Site ST-27 (i.e., SVE and biosparging would be implemented from 1997 to 2000).

9.2 REVIEW OF SCREENING AND EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for soil and groundwater contamination at Site ST-27 were adapted from those recommended by USEPA (1988) for selecting remedial actions for Superfund sites [Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-01]. These criteria are consistent with those required for initial screening and detailed evaluation of remedial alternatives by the SCDHEC (1995). These criteria include (1) anticipated effectiveness in meeting target cleanup criteria, (2) technical and administrative implementability, and (3) relative cost. An initial screening of remedial technologies was conducted using the three broad evaluation criteria (Appendix H). The following sections briefly describe the scope and purpose of each criterion.

9.2.1 Effectiveness

Each remedial approach or remedial alternative (which can be a combination of remedial technologies) was evaluated to determine how effectively it can attain the desired degree of cleanup. Remedial approaches that could not cost-effectively attain the desired level of remediation were eliminated from further consideration. The candidate alternatives for Site ST-27 are designed to attain the Tier 2 SSTLs for Site ST-27. Section 7 provides the rationale for and development of the SSTLs for the site,

given the current and planned future land uses and the potential for receptor exposures to site-related contamination.

Remedial options retained for detailed evaluation are compared in terms of the expected effectiveness of each option to attain the desired degree of risk reduction at Site ST-27, based on site-specific data supplemented with treatability test data collected at the site. The ability to minimize potentially adverse impacts on surrounding facilities and operations and other environmental resources is considered. Time to implementation and time until protection is achieved are described. Potentially adverse impacts that could be realized during implementation, the cost of necessary mitigation measures, and the potential for residual risks remaining following remedial action also were qualitatively considered. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also is evaluated.

9.2.2 Implementability

The technical feasibility, applicability, and reliability of each remedial approach were initially used as broad criteria to narrow the list of potentially applicable remedial approaches for the site. Technologies retained for detailed evaluation were evaluated in terms of engineering implementation, reliability, constructability, and technical/logistical feasibility. Potential effects due to unanticipated site conditions or significant changes in site conditions were considered. The ability to monitor performance and public perception are discussed. Any prohibition of onsite activities that would be required to ensure successful implementation is described.

9.2.3 Cost

Relative cost of various remedial technologies was used as an initial screening tool (Appendix H). More detailed cost estimates were prepared for each remedial alternative developed for comparative analysis. The cost includes operation and maintenance costs over the time required for implementation. Present-worth cost estimates were prepared using a 7 percent annual adjustment factor in accordance with USEPA (1993) guidance.

9.3 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

In this section, each of the candidate alternatives is evaluated using the criteria described in the previous section. Each alternative is more fully described in terms of its effectiveness, technical and administrative implementability, and cost.

9.3.1 Alternative 1 - SVE as an Interim Action, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

9.3.1.1 Effectiveness

Soil gas, soil, and groundwater sampling performed at Site ST-27 in 1995 indicates that no contaminants are present at concentrations that would cause an unacceptable risk to potential human and ecological receptors because no significant exposure pathway is or will be completed. However, contaminants were measured in soils at concentrations

above those that are protective of underlying groundwater. The remaining LNAPL at the site also will act as a source of contaminant mass to groundwater over time. Simple source term calculations (Section 6) indicate that these two sources may cause increases in dissolved plume concentrations and some limited plume expansion over the next few years. An SVE system has been installed and is operating at the site to reduce soil gas concentrations to approximately one-half the LEL for MOGAS (i.e., to mitigate potential explosive hazards and prevent exceedances of PELs in ambient air if the concrete apron is removed). It is anticipated that the soil gas VOC concentrations can be reduced to these levels within 3 to 6 months of SVE system operation. Monthly TVH soil gas field screening and analytical sampling will be performed at all soil gas monitoring points to verify soil gas contaminant reductions. Additional details on soil gas sampling are presented in the LTMP in Section 10 of this CAP. SVE at Site ST-27 will be discontinued once equilibrium soil gas concentrations have been reduced to about 5,000 ppmv TVH. For cost estimation purposes, it was assumed that the expanded SVE system will operate continuously for 6 months.

Modeling results presented in Section 6 indicate that contaminant concentrations in soil and groundwater will increase in the short-term and then decrease slowly over time through both destructive and nondestructive attenuation processes. Natural chemical attenuation processes should be sufficient to reduce dissolved COPCs to the most restrictive Tier 2 SSTLs in approximately 21 years (i.e., 1996 to 2017). This estimate is based on an assumption that no further releases of fuel will occur at Site ST-27. The assimilative capacity of the saturated media and the site-specific biodegradation rates will be sufficient to eventually transform fuel hydrocarbon compounds into carbon dioxide and water and to limit migration of the plume. It should be noted, however, that the hydrogeology of the site is the primary mechanism responsible for the containment of the plume at the site. The very low horizontal hydraulic gradient at the site is preventing contaminants from migrating appreciable distances from the source area.

Contaminant mass will slowly partition from mobile and residual LNAPL and dissolve into groundwater. Weathering estimates presented in Section 6.6 suggest that mobile LNAPL at the site will no longer be a significant source of contaminant mass in about 10 to 12 years. However, this analysis is based on the assumption that no further releases of fuel will occur. As a result of a leak detected in the gasoline supply pipeline, the gasoline tank and pipeline were deactivated in April 1996, and remaining product was removed from the system. The entire fueling facility is scheduled for removal in 1997. Residual soil contamination also is expected to be a source of contamination for about 10 years as a result of slow leaching processes. When these two significant but diminishing source terms are included in the analytical model for the site, the dissolved plume is expected to increase slightly in size and concentration over the next few years, but to stabilize by the year 2003 and be reduced below the most restrictive SSTLs within 21 years.

Groundwater use controls are an important component of this alternative. The current restrictions on site access (Base perimeter fencing) provide a measure of protection against unauthorized site access and groundwater contact. The 14-inch reinforced concrete that covers the site also limits the potential for onsite personnel exposure to contamination. The present industrial/uninhabited land use and nonuse of

groundwater have effectively interrupted potential exposure pathways involving soil and groundwater at this site. As a part of this CAP, the Air Force proposes well permit restrictions to prevent withdrawal of groundwater from the shallow aquifer for drinking water applications within 1,000 feet of the leading edge of the current plume until such time as the groundwater COPCs decrease below applicable RBSLs. Excavation in the area of contaminated shallow groundwater also should be limited to prevent incidental contact with contamination. Groundwater use restrictions should be a component of any future land use change or property exchange until such time as unrestricted RBSLs have been achieved. This strategy will not interfere with the current and intended use of the site and affected physical media. In the unlikely event that the site is released from government ownership and rezoned for unrestricted residential use within the next 25 years, groundwater use restrictions must be kept in place and enforced until such time as COPCs have been reduced to concentrations equal to or below unrestricted use RBSLs at every point. Tier 2 SSTLs may or may not be appropriate cleanup criteria if the site is released from government control and land use can no longer be effectively controlled.

Long-term groundwater monitoring is recommended under Alternative 1 as a method of measuring the effectiveness of natural chemical attenuation. The groundwater monitoring network would consist of 13 existing groundwater monitoring wells. These wells would be sampled semiannually for 2 years and annually thereafter for all COPCs. Sampling details are presented in the LTMP presented in Section 10. Based on sampling results, the migration of the contaminant plume will be monitored. If it appears that the plume is well characterized and moving slowly, sampling frequency would be reduced to every other year. If it appears that the plume is moving rapidly or is not well defined or contained, annual sampling would continue until the plume is well characterized. At that time, samples would be collected every other year until the plume stabilizes and concentrations have been reduced below the most restrictive Tier 2 SSTLs. Once the plume is stable and SSTLs are attained, 2 years of annual verification sampling is proposed to verify no adverse change in plume conditions before requesting regulatory approval for a Tier 2 closure.

For the purpose of cost estimation, sampling was assumed to occur semiannually for the first 2 years and annually thereafter for the first 20 years (i.e., from 1997 to 2017) and every year for the next 2 years (i.e., until 2019) to verify attainment of SSTLs before requesting approval for site closure.

A complete LTMP is provided in Section 10 to assist the Base in implementing long-term groundwater monitoring. Parsons ES has been retained to complete the first year of groundwater monitoring at Site ST-27. Data from each sampling event should be compared to model predictions to ensure that natural attenuation is preventing the contaminant plume from spreading further than was predicted by the conservative model. In the event that remediation is not progressing as expected and/or the dissolved plume is migrating further or faster than expected, the following contingency actions are recommended:

- Resample all downgradient sentry and POA wells to confirm initial results;

- Evaluate the results of the most recent groundwater sampling event to determine if there is a trend indicating more rapid contaminant migration due to a lack of natural attenuation or misinterpretation of site hydrogeology;

- Determine if the levels of groundwater contamination present an unacceptable risk to potential receptors given actual site and downgradient land use at the time of sampling (i.e., are exposure pathways complete?); and

- If a significant risk exists, reevaluate more active methods of remediation and implement the most effective risk-reduction method (e.g., the active remediation methods described for Alternatives 2 or 3).

9.3.1.2 Technical and Administrative Implementability

Alternative 1 is technically simple and easy to implement. No additional groundwater monitoring wells would be required to monitor the area downgradient from the current plume. Several existing wells are far enough downgradient to serve as POA wells should the plume shift directions, as has been noted during previous sampling events (see Figure 3.4). Long-term groundwater sampling is a standard procedure involving minimal worker exposure to contaminated media. The equipment required for the SVE interim action has already been installed and is operating. The VR Systems® ICE extraction and treatment unit has performed well during pilot testing (Section 8) and requires a minimum amount of maintenance and upkeep. It is reasonable to assume that the expanded system can be operated for an additional 3 to 6 months without any operational problems.

Administrative implementation of this alternative would require that Charleston AFB personnel communicate plans regarding the future use of the Base and specifically Site ST-27 to the public and SCDHEC. Any proposed change in land use that differs from industrial use, or any proposed groundwater pumping within 1,000 feet of the leading edge of the current plume, should be carefully evaluated. The existing access restrictions also should be maintained to prevent unauthorized access. Any future construction or maintenance activities in this area should be planned to minimize excavation (i.e., any ground disturbance below the concrete covering the area) until health-protective SSTLs have been achieved and to protect the network of LTM wells. Wells should remain locked and protected against tampering or vandalism.

Public perception of Alternative 1 could be somewhat negative. This alternative should be adequately protective of human and ecological receptors if current institutional controls are maintained. Although no unacceptable risk exists at this site, contaminant concentrations that exceed Tier 2 SSTLs (and Tier 1 RBSLs) for soil and groundwater would remain onsite for a lengthy period of time. It is anticipated that public reaction to allowing contaminants in excess of Tier 2 SSTLs to persist onsite with minimal engineered remediation may not be positive. To counteract potentially negative public opinion, public education would be a prominent part of this alternative and would focus on the site-specific risk analysis and cost savings. Human risk can be mitigated through institutional controls, and COPC reductions that are compatible with existing and future land use would be achieved at minimum taxpayer expense. Consistent LTM would provide verification of natural attenuation and ensure that site conditions do not change adversely over time.

9.3.1.3 Cost

The costs associated with Alternative 1 are presented in Table 9.1. Detailed cost calculations are presented in Appendix H. The SVE system will require periodic system monitoring to ensure proper operation. The majority of this monitoring can be performed remotely via a modem hookup to an onboard controller on the ICE. It is anticipated that monthly site visits will be sufficient to maintain the SVE system. Annual or periodic costs would include soil gas and groundwater monitoring and site management (to be provided by Charleston AFB), which would include evaluation of annual monitoring data, continued liaison with SCDHEC and the public, and participation in future land use planning. Based on the conservative assumption that 21 years of natural chemical attenuation with 22 LTM sampling events (i.e., 1997 to 2017, every other year) followed by 2 years of verification sampling would be required to document plume stability and achieve Tier 2 SSTLs, the present-worth cost of Alternative 1 is estimated to be $333,511. These costs are most sensitive to unexpected delays in reducing soil gas to 5,000 ppmv, attaining plume stabilization, and/or achieving the most restrictive Tier 2 SSTLs. For example, if 2 additional sampling events are required to show no further increases in concentration or plume size, the present-worth cost of this alternative would increase to $339,743.

9.3.2 Alternative 2 - SVE as an Interim Action, *In Situ* Bioventing in Source Area, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

9.3.2.1 Effectiveness

In addition to relying on the mass removal effects of natural biodegradation processes and the limited range of area that can be impacted due to hydrogeologic conditions, the effectiveness of Alternative 2 in minimizing plume migration and reducing contaminant concentrations at Site ST-27 would rely on additional source reduction activities. SVE followed by bioventing is expected to have little effect in the short-term on the area impacted by dissolved contamination originating from Site ST-27. SVE would be employed at Site ST-27 under this alternative as an interim action to immediately remediate contaminated soil gas that may present an explosive or human health hazard. Bioventing would be implemented as the source area soil remediation technology following the interim action. Based on the results of the pilot-scale SVE and bioventing tests already performed at Sites ST-27 and ST-41 at Charleston AFB, both technologies will efficiently and cost-effectively remediate fuel-related contamination in soil gas and unsaturated soils. Bioventing is a more cost-effective soil remedial approach than SVE, and would be used to remediate vadose zone soils and to reduce the overall mass of COPCs entering the groundwater. Bioventing will also enhance the treatment of the small quantity of LNAPL remaining on the site. During periods of low groundwater elevation, LNAPL will be smeared in the soil and more

TABLE 9.1
COST ESTIMATE FOR ALTERNATIVE 1
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Implementation Tasks	**Capital Costs**
Short-term SVE operation	$16,896
Confirmatory soil gas sampling at 10 locations	$6,164
Site Management and Monitoring Tasks	**Annual Costs**
Groundwater sampling at 13 existing wells	
In accordance with Long-Term Monitoring Plan	$32,270 (yrs 1+2) $16,135 (yrs 3-22)
Site Management(22 years)[a/]	$9,600
Present Worth of Alternative 1[b/]	**$333,511**

[a/] Assuming sampling 2 times per year for 2 years and 1 time per year thereafter to attainment of SSTLs followed by 2 years annual verification sampling.
[b/] Based on an annual discount rate of 7 percent.

available for air(oxygen) contact and enhanced biodegradation. Natural chemical attenuation would be the only remedial approach prescribed for the remediation of dissolved contamination in groundwater at Site ST-27 under this alternative.

The analytical model predicts that, even if both LNAPL and residual soil contamination can be appreciably reduced, the dissolved plume would persist at concentrations above the most restrictive Tier 2 SSTLs for about 11 years (i.e., 1996 until 2007). Although total contaminant mass would be reduced in the source area as a result of SVE and bioventing, the analytical model predicts that detectable dissolved concentrations could migrate approximately 60 feet further downgradient during the next 8 to 10 years (Figure 9.2).

The total area of groundwater that could be impacted by the release at Site ST-27 would not be significantly different under this alternative than would be expected if no engineered source reduction activities were conducted at this site. The analytical model developed for this site is conservative, thus allowing maximum contaminant migration. However, two major benefits can be derived from implementing source reduction activities at Site ST-27. First, SVE will immediately remove hazardous vapors from the shallow subsurface in the vicinity of Building 575. This will eliminate potential explosive hazard concerns and minimize vapor migration into the outdoor breathing zone of onsite workers should the concrete apron be removed. Secondly, both SVE and bioventing would reduce the total contaminant mass that could eventually be released into the environment, particularly into underlying groundwater. Bioventing treats residual soil contamination more cost-effectively than SVE because no off-gas treatment is required. As a result, bioventing will be implemented at the site as soon as soil gas contaminant concentrations are reduced to approximately 5,000 ppmv to minimize concerns about vapor migration.

The groundwater use controls for this alternative would be identical to those described for Alternative 1. The installation and operation of the bioventing system would require additional site access. The long-term groundwater monitoring proposed for Alternative 2 would be identical to Alternative 1. The bioventing system would require system maintenance checks every other week (by Charleston AFB personnel) and semi-annual respiration and oxygen influence testing to ensure proper operation. The bioventing system is a simpler system than the SVE system currently operating at the site, and will require minimum maintenance during its 2 years of operation.

9.3.2.2 Technical and Administrative Implementability

Although Alternative 2 also would not require installation of additional groundwater monitoring wells, the SVE system would have to be converted to a bioventing system once soil gas TVH concentrations are reduced to approximately 5,000 ppmv. This system conversion would not be technically difficult because the HVWs can be easily used for injection of air as well. One small centrifugal blower would be installed to supply 30 to 50 scfm of air to the horizontal wells at the site. Electrical service is available at Building 575, and the new bioventing blower would be placed in a small shed next to the building.

As described for Alternative 1, existing groundwater monitoring wells are well placed to be used for model verification and compliance monitoring. Several wells are

far enough downgradient to serve as POA wells should the plume migrate in a direction other than its current west-southwesterly direction.

The general reliability and maintainability of SVE and bioventing systems is high. One HVW and the SVE system have been operating at the site since February 1996 without any significant maintenance problems. The VR Systems® ICE is equipped with a telemetry system that allows remote monitoring through a modem and an on-board computer monitoring system. This allows remote monitoring of the system on a daily basis. In comparison to the SVE system, the bioventing system will be a simple mechanical system. The motor bearings on the blower motor are sealed and do not require lubrication. In-line air filters and automatic pressure relief valves provide protection for the air injection blower. Filters generally require replacement after every 90 to 180 days of operation. It is estimated that the SVE system will continue to operate for 3 to 6 months as an interim action to treat elevated soil gas concentrations. The bioventing system would be installed after the SVE system is removed and would operate for 1 to 2 years to lower soil contaminant concentrations to levels that are protective of groundwater underlying the source area (i.e., equal to or below the Tier 2 soil leaching SSTLs).

Administrative implementation of this alternative would be similar to that described for Alternative 1, and would require that Charleston AFB personnel communicate with the public and SCDHEC regarding the future use of the site (i.e., continued industrial use). Appropriate land use restrictions must be upheld to prevent unnecessary exposure of humans to contaminated groundwater. Access to the site should continue to be restricted by the Base perimeter fences. Any future site development plans should protect the SVE and bioventing systems, the HVWs associated with the systems, and the network of LTM wells. Wells should remain locked and protected against damage.

The public perception of Alternative 2 would be expected to be more positive than Alternative 1. In addition to offering immediate protection of onsite workers through hazardous vapor recovery using the SVE system, this alternative could reduce COPC concentrations to below Tier 2 SSTLs (and possibly RBSLs) at a relatively low cost. SVE and bioventing are expected to expedite the attenuation of dissolved contamination downgradient from the source area because less contaminant mass will be added to groundwater over time. The primary advantage of Alternative 2 is that it would assure attainment of soil SSTLs within approximately 2 years and expedite attainment of the most restrictive SSTLs in the groundwater. COPC reductions that are compatible with existing and future land use would be achieved at minimum taxpayer expense. LTM would verify the effectiveness of the implemented remedy and ensure that site conditions do not change adversely over time.

9.3.2.3 Cost

The costs associated with Alternative 2 are presented in Table 9.2. Detailed cost calculations are presented in Appendix H. Six months of SVE operation and monitoring and 2 years of bioventing operation and monitoring have been estimated.

TABLE 9.2
COST ESTIMATE FOR ALTERNATIVE 2
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Implementation Tasks	**Capital Costs**
Short-term SVE/ICE operation	\$16,896
Confirmatory soil gas sampling at 10 locations	\$6,164
Design and installation of bioventing system	\$17,776
Future Tasks	**Future Cost**
Confirmatory soil sampling following bioventing	\$15,172
Site Management and Monitoring Tasks	**Annual Costs**
Operation/maintenance of bioventing system (2 years)	\$9,476
Groundwater sampling at 13 locations (12 years)[a/]	\$32,270 (yrs 1+2) \$16,135 (yrs 3-12)
Site Management (12 years)[a/]	\$9,600
Present Worth of Proposed Corrective Action[b/]	**\$303,349**

[a/] Assuming sampling two times per year for the first 2 years and one time per year for 8 years followed by 2 years of annual verification sampling.
[b/] Based on an annual discount rate of 7 percent.

Other costs include groundwater monitoring semiannually for 2 years and annually thereafter for 10 years (i.e., until 2007), 2 years of annual verification sampling, annual site management (provided by Charleston AFB), which would include public education, continued liaison with SCDHEC, participation in future land use planning, and closure soil sampling. Using these assumptions, the present-worth cost of Alternative 2 is $303,349. Alternative 2 costs are most sensitive to extended operation of the SVE system to achieve a target VOC equilibrium concentration of 5,000 ppmv, extended operation of the bioventing system to achieve Tier 2 soil leaching SSTLs, and extended groundwater monitoring to document plume stability, and/or attainment of the most restrictive SSTLs.

9.3.3 Alternative 3 - SVE as an Interim Action, *In Situ* Biosparging in Source Area, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

9.3.3.1 Effectiveness

The effectiveness of Alternative 3 in reducing site contaminants to levels below Tier 2 SSTLs would depend upon a combination of SVE, biosparging for *in situ* groundwater treatment, and long-term natural attenuation. The SVE system at the site would continue to be operated as an interim action as described in Alternatives 1 and 2. Additionally, the SVE system would be expanded to support the operation of a biosparging system throughout the source area at Site ST-27. The biosparging system would be designed to inject air below the groundwater surface at the site to promote biodegradation of COPCs in groundwater. The biosparging system also would volatilize dissolved contaminants in groundwater and in unsaturated soils as air is forced through the contaminated media. The SVE system would be used to capture injected air and prevent migration of contaminant vapors into the atmosphere or surrounding structures. Natural attenuation processes would be relied upon to remediate any dissolved contamination that has migrated beyond the zone of influence of the biosparging system. Natural attenuation will be enhanced by the addition of DO to the groundwater by the biosparging system.

During modeling, it was conservatively estimated that 1 mg/L of DO could be added to groundwater by the biosparging injection wells (Appendix E). The analytical model for this alternative predicts that by the year 2000 the maximum concentration of dissolved benzene in the source area will be half the concentration expected if only interim SVE soil remediation and natural attenuation processes are relied upon to reduce contaminant concentrations. Figure 9.4 compares the predicted effectiveness of SVE/biosparging (Alternative 3) to SVE/bioventing (Alternative 2) on dissolved contamination over time.

It is important to note that SVE/biosparging slightly enhances source area remediation, but does not expedite remediation of dissolved contamination that is beyond the projected radius of influence of the full-scale system. Reductions in contaminant mass in these areas is solely due to natural chemical attenuation processes. Hence, the anticipated contaminant distribution pattern over time at the site will change from a typical dissolved plume with maximum concentrations centered near the source area to a "donut-like" plume with reduced contaminant concentrations in the treated

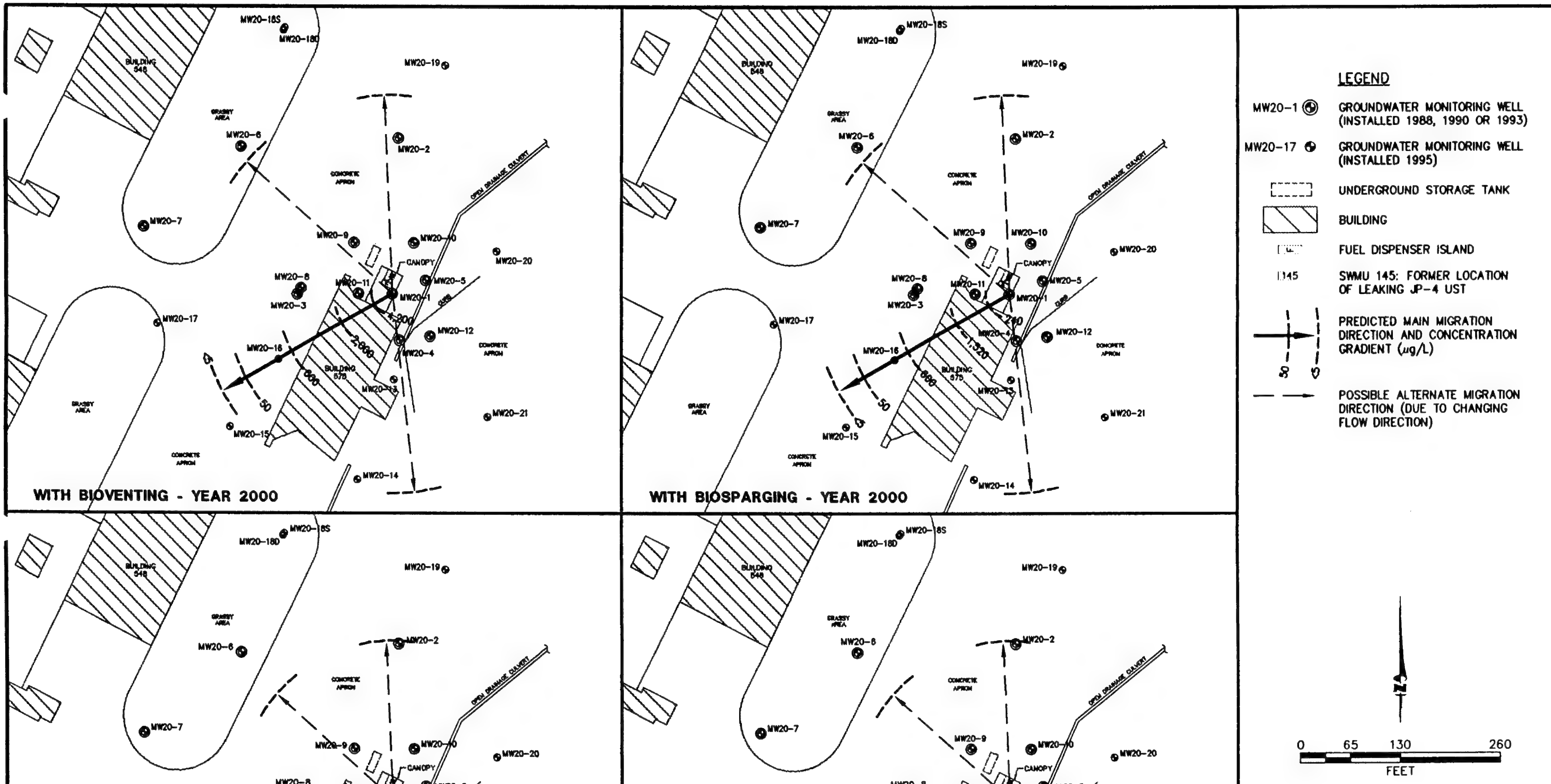

FIGURE 9.4

IMPACT OF SVE/BIOSPARGING ON DISSOLVED BENZENE PLUME OVER TIME

Site ST-27 Corrective Action Plan
Risk-Based Approach To Remediation
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source area and elevated but diminishing contaminant concentrations on the plume fringes (Figure 9.4).

A biosparging pilot test would be performed at Site ST-27 prior to full-scale design. The conceptual design presented and discussed in this section is based on previous experience at similar sites (Acomb *et al.*, 1995). Results from the pilot test, if deemed necessary to implement the selected risk-based remedy, would be used to refine the conceptual design and determine design variables such as well spacing, injection depth and rate, and required injection pressure.

One drawback to the effectiveness of this alternative would be the expected lead time and administrative effort required to pilot test, design, permit, and construct the expanded SVE and biosparging systems. The installation and operation of the biosparging system also would require limited concrete cutting and repair and may create a short-term disruption of military operations. The biosparging system would require weekly system checks. SVE system monitoring would be facilitated by the telemetry system installed on the ICE, although monthly site visits for basic system maintenance would be required.

9.3.3.2 Technical and Administrative Implementability

Both vertical and horizontal well configurations were initially considered for the biosparging well network. Biosparging with vertical wells would require installation of 41 air injection wells to achieve uniform sparging throughout the SVE area of influence (Figure 9.1), based on a 10-foot radius of influence for each injection well. In addition to the concrete cutting required for the 41 wells bores, it would be necessary to cut an additional 740 linear feet of concrete for air transfer lines. The extensive concrete removal is not only expensive, but also would jeopardize the structural integrity of the overall tarmac near Building 575. Thus, horizontal boring techniques were evaluated for installation of air transfer lines for the vertical well configuration and for installation of horizontal air injection wells (HAIW). The biosparging and SVE systems, including blowers and the ICE vapor treatment system, would be constructed of common remedial equipment that is or could easily be installed at Site ST-27. Electrical power for the extraction and injection blowers is available at Building 575. For this engineering estimate, it was assumed that the biosparging system would be installed inside a small wooden shed similar to a bioventing installation.

Positive-displacement blowers (to be used for the biosparging system) generally are reliable when they are properly maintained. A weekly monitoring schedule would be developed and implemented for all of the mechanical systems installed as part of this alternative. To reduce source area groundwater concentrations to the most restrictive SSTLs, the biosparging and SVE systems would need to be operated for and estimated about 3 years (i.e., from 1997 to 2000). It is important to note that the SVE system can operate independent of the biosparging system. However, to assure that COPCs are not forced into buildings or the atmosphere, the biosparging system should not be operated without concurrent operation of the SVE system. The large quantity of air used for biosparging (200 scfm) will require an extraction system to prevent undesirable vapor migration.

The same groundwater monitoring well network described in Alternative 1 would be necessary to monitor the natural attenuation at the dissolved plume and to verify the effectiveness of the biosparging system in removing volatile COPCs and increasing DO in source area groundwater. The network of LTM wells for Alternative 3 would consist of a total of 13 groundwater monitoring wells.

Administrative implementation of this alternative would require that Charleston AFB continue to communicate with SCHDEC and the public regarding the future use of Site ST-27. The Base perimeter fence and cement cover of the site should be maintained to prevent unauthorized entrance and direct contact with impacted site media. Any future land use plans should protect the biosparging and SVE systems and network of long-term monitoring wells. Wells should remain locked and protected against tampering.

Public perception of Alternative 3 would be expected to be positive. However, most experienced remediation professionals would view this level of treatment as excessive, given that the site is used for industrial use and the risk of offsite contaminant migration and onsite and offsite receptor exposure is very low. This alternative would be protective of human health, and would achieve COPC reductions that are compatible with industrial land use. However, any benefits of more rapid risk reduction may not be justified, given the additional cost.

9.3.3.3 Cost

Vertical or horizontal injection well configurations could be installed for biosparging operations. However, as discussed in Section 9.3.3.2, both configurations would require horizontal borings to ensure that the structural integrity of the concrete tarmac surrounding Building 575 is not jeopardized. Costs to install horizontal boreholes for the air transfer lines for the vertical air injection well configuration are nearly equivalent to the costs of installing the HAIW configuration. However, the vertical air injection well configuration also would require installation of the 41 vertical air injection wells and tie-ins for these wells into the air transfer lines. Thus, the vertical air injection well configuration could be significantly more expensive than the HAIW configuration. A HAIW network is proposed for the biosparging system included in Alternative 3.

The costs associated with Alternative 3 are presented in Table 9.3. Detailed cost calculations are included in Appendix H. Capital costs include the cost of design and construction of the biosparging system. Annual costs would include 3 years of SVE and biosparging, and 11 years of long-term groundwater monitoring, verification sampling, and site management to demonstrate uniform reductions in contaminant levels. Based on these assumptions, the present-worth cost of Alternative 3 is $662,738. Alternative 3 costs are most sensitive to additional years of biosparging and SVE systems operation and maintenance and LTM to demonstrate plume stability and attainment of the most restrictive SSTLs.

TABLE 9.3
COST ESTIMATE FOR ALTERNATIVE 3
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Implementation Tasks	**Capital Costs**
Short-term SVE operation	$16,896
Confirmatory soil gas sampling at 10 locations	$6,164
Design and installation of full-scale SVE and biosparging system	$331,000
Future Tasks	**Future Cost**
Confirmatory soil sampling following SVE/biosparging	$26,292
Site Management and Monitoring Tasks	**Annual Costs**
Operation/maintenance of SVE/biosparging system (3 years)	$25,402
Groundwater sampling at 13 existing wells in accordance with Long-Term Monitoring Plan (11 years)[a]	$32,270 (yrs 1+2) $16,135 (yrs 3-11)
Site Management (11 years)	$9,600
Present Worth of Alternative 3[b]	**$662,738**

[a] Assuming semiannual sampling for the 2 years, annual sampling for the next 7 years followed by 2 years annual verification sampling.
[b] Based on an annual discount rate of 7 percent.

9.4 RECOMMENDED ALTERNATIVE

Alternative 2 (SVE as an Interim Action, *In Situ* Bioventing in Source Area, Natural Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls) is recommended for remediation of Site ST-27 based on its expected effectiveness in stabilizing the dissolved plume and attaining Tier 2 SSTLs, its relative simplicity with respect to technical and administrative implementation, and its relatively low overall cost. Table 9.4 provides a summary of the evaluation process for each alternative.

The conservative analytical model suggests that the implementation of bioventing after SVE in the source area could reduce the total mass of contaminants that could be introduced into the groundwater over time at Site ST-27. As discussed in Section 8 and summarized in this section, there is considerable evidence that SVE followed by *in situ* bioventing will effectively reduce fuel-related contamination in soil gas and soils in the vicinity of the source area at Site ST-27. Most importantly, SVE will immediately remove potentially explosive or hazardous concentrations of fuel vapors from shallow subsurface soils.

Significant evidence exists that natural physical, chemical, and biological conditions at Site ST-27 will limit the migration of the dissolved contaminant plume. Currently, the dissolved plume extends approximately 200 feet downgradient from the source area at Site ST-27. Based on the conservative analytical model, once the source of BTEX has been reduced by SVE and bioventing, the plume is expected to stabilize approximately 260 feet downgradient from the source area before it begins to decrease in concentration and size. It is important to note that the concentration and total mass of dissolved contaminants will be continually reduced by natural destructive attenuation processes. Due to the conservative nature of the analytical model, the site may actually meet Tier 2 SSTLs sooner than anticipated.

Given the current and projected industrial land use at Site ST-27 and in surrounding areas, no active groundwater remediation is required at this site to protect human health or the environment (i.e., there is not a completed exposure pathway at the site). Conservative modeling (Section 6) predicted limited soil gas volatilization into indoor and outdoor air under natural convective/diffusive processes and limited downgradient plume migration, with no off-Base migration. Long-term groundwater monitoring will be used to verify the effectiveness of natural attenuation and to assure that COPCs do not migrate beyond the area under reliable exposure controls. Limitations on groundwater pumping at this site should not affect future land use or operations.

Although Alternative 3 could further limit plume migration and minimize monitoring of costs, the cost of constructing and maintaining a biosparging treatment system at this site is not justified given that no current risk associated with groundwater exists, and no future risk or off-Base contaminant migration is expected. Alternative 3 could be implemented if future land use plans require more immediate groundwater use.

TABLE 9.4
SUMMARY OF REMEDIAL ALTERNATIVE EVALUATION
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			$333,511
-SVE as an Interim Action -Natural Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Contaminant mass, volume, and toxicity will gradually be reduced by natural attenuation alone. Most restrictive Tier 2 SSTLs will be met in approximately 20 years.	Technically simple and easy to implement. Long-term groundwater monitoring for 22 years is required. Groundwater use restrictions need to be implemented and would not incur any additional land use restriction beyond those currently in place at Site ST-27. Requires public education.	
Alternative 2			$303,349
-SVE as an Interim Action -*In Situ* Bioventing in Source Area -Natural Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 1, with the addition of bioventing to increase contaminant removal and degradation in the source area. Attainment of the most restrictive Tier 2 SSTLs in approximately 10 years. Pilot testing indicated bioventing will significantly remove BTEX compounds from unsaturated soils.	Long-term groundwater monitoring for 12 years is expected. The bioventing system is expected to operate for 2 years. This system will require weekly monitoring. Groundwater and land use restrictions would be the same as Alternative 1. Positive public perception.	
Alternative 3			$662,738
-SVE -*In Situ* Biosparging in Source Area -Natural Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 2, with biosparging for the active remediation of groundwater contamination. Tier 2 SSTLs will be met in approximately 9 years.	Operation of the biosparging/SVE system for 3 years is expected. Long-term groundwater monitoring for 11 years will be required. Lengthy lead time required for design and installation of groundwater biosparging system. Positive public perception.	

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On the basis of this evaluation, Alternative 2 provides the best combination of risk reduction and low cost without imposing additional land use restrictions. Section 10 provides additional details on the recommended implementation of this alternative.

SECTION 10

IMPLEMENTATION OF THE RECOMMENDED RISK-BASED CORRECTIVE ACTIONS

This section provides an implementation plan for the recommended risk-based corrective action for Site ST-27 (i.e., Alternative 2: SVE followed by bioventing in source area soils, natural chemical attenuation, monitoring of groundwater to verify plume stability, and land and groundwater use controls). This section presents the scope, schedule, and costs for the implementation of the selected remedial alternative.

10.1 SCOPE OF REMEDIAL ACTIVITIES

The recommended remedial action alternative will be implemented over an 11- to 13-year period to ensure that contamination in all media at Site ST-27 is reduced sufficiently to attain and can maintain the SSTLs presented in Section 7. The following sequence of events is proposed to fully implement this remedial action.

10.1.1 Review and Approval of Corrective Action Plan

Approval of this CAP is within the authority of Charleston AFB, SCDHEC, and AFCEE personnel. This group of environmental professionals is responsible for review of this CAP and eventual implementation of the approved remedial actions. A final draft of this document was distributed to each of the above organizations for review and comment. Comments were received from all reviewers and incorporated into this final version of the CAP.

Based on the recommendations of this CAP, the Air Force intends to install and operate a source reduction remedy (SVE/bioventing) and apply for a "Groundwater Mixing Zone" variance for this site. Based on the information presented in this CAP, Site ST-27 contamination poses no threat to drinking or surface waters of the State and is an excellent candidate for a mixing zone variance.

10.1.2 Full-Scale SVE System Design, Installation, and Operation

To complete the pilot testing objectives, one existing and one new HVW at Site ST-27 were connected to a VR Systems® V2C ICE located adjacent to Buildings 575 in June 1996 (Figure 10.1). The HVWs are placed to extract fuel vapors from soils known to be most contaminated based on previous soil sampling events. The 4-inch-diameter HVWs are screened in the interval of unsaturated soil contamination immediately above groundwater in the source area at Site ST-27, generally at a depth of 3 to 5 feet bgs. Based on an expected radius of influence of 50 feet, approximately 23,700 square feet will be treated by the two HVWs and SVE system.

During system startup, air extraction rates and vacuums were optimized for each HVW to maximize contaminant volatilization and biodegradation potential. Flow was balanced between the two HVWs to maximize TVH concentrations in the ICE influent stream and to minimize the need for supplemental fuel. Initial soil gas samples were collected before system startup from selected VMPs and analyzed for oxygen, carbon dioxide, and TVH using direct-reading instruments. Additionally, initial and periodic air samples were collected from VMPs in 1-liter SUMMA® canisters and submitted for laboratory analysis of TVH and BTEX using USEPA Method TO-3. These results will be compared to subsequent sampling results to determine the reduction of TVH concentrations during system operation. The same field parameters will be measured in samples collected from the influent and effluent sides of the VR Systems® ICE to determine TVH destruction efficiency.

With SCDHEC acceptance of this CAP, the SVE system will be designated as a full-scale treatment project and operated for approximately 6 total months. Extraction flow rates will require periodic adjustments throughout this period of operation to maintain optimum TVH concentrations. At the conclusion of approximately 6 months of operation, comfirmatory air samples will be collected from all the VMPs at Site ST-27 to determine the degree of contaminant reduction and to evaluate the transition from SVE to bioventing operations. Based on results from the SVE pilot test performed at Site ST-27 (Section 7.2), 6 months should be adequate to reduce equilibrium soil gas TVH concentrations to levels well below one-half the LEL of MOGAS (i.e., 5,000 ppmv). Once TVH soil gas concentrations have been reduced to acceptable levels, the SVE system will be converted to an air injection bioventing system. Additional details on system operation and maintenance, compliance sampling, and abandonment procedures can be found in Section 10.3, the LTMP, and Appendix I, the SAP.

10.1.3 Bioventing System Design, Installation, and Operation

The two SVE HVWs will be used as bioventing air injection wells once equilibrium soil vapor TVH concentrations are reduced to approximately 5,000 ppmv. The change from air extraction to air injection is expected to occur after approximately 6 months of SVE. VMP and blower locations are shown on Figure 10.1.

During the startup of the bioventing system, air injection rates will be optimized to minimize contaminant volatilization and maximize biodegradation potential. After system startup and optimization, periodic monitoring of the system will be required. The system will be checked by base personnel every other week to assure proper operation. The air injection temperature and pressures will be recorded, and the inlet air filter will be changed as necessary. Every 6 months during system operation, *in situ* respiration testing will be performed by Parsons ES to assess soil contaminant biodegradation rates at Site ST-27. Results of testing activities will be provided to Charleston AFB, SCDHEC, and AFCEE to update all parties involved on remediation progress.

At the conclusion of approximately 2 years of bioventing operations, compliance soil samples will be collected to determine the degree of contaminant reduction. If contaminant levels have been reduced to acceptable levels (i.e., below the Tier 2 soil leaching SSTLs), the bioventing system will be deactivated. Based on results from the pilot tests performed at Site ST-27 (Section 7.1), 2 years should be adequate to reduce

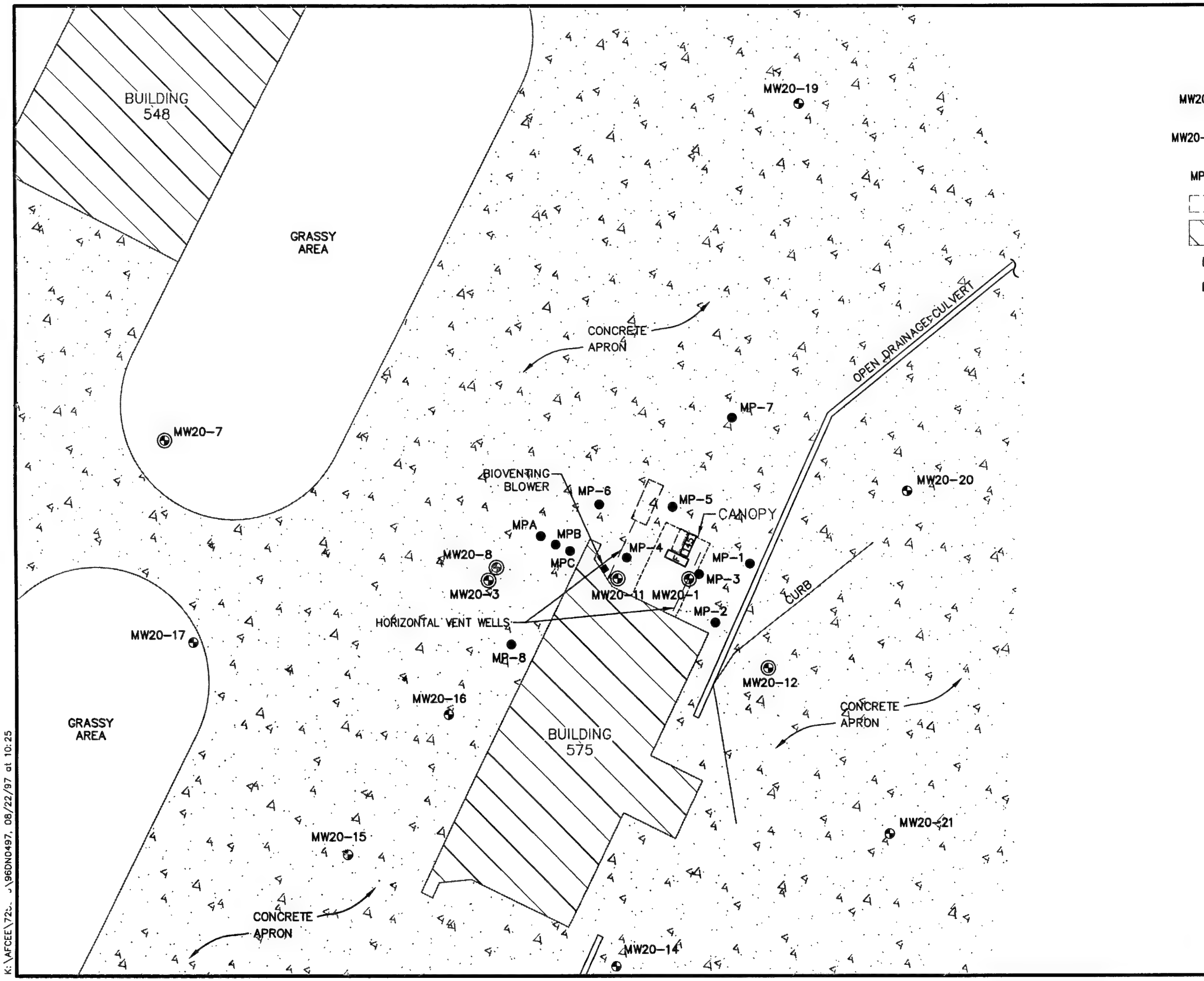

FIGURE 10.1

SVE SYSTEM LAYOUT AND LTM WELLS

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COPC concentrations in contaminated soils at Site ST-27 to below Tier 2 soil leaching SSTLs. Additional details on system operation and maintenance, compliance sampling, and abandonment procedures can be found in Section 10.3, and Appendix I.

10.1.4 Verification of Land and Groundwater Use Controls

An important element of the recommended corrective action at Site ST-27 is land and groundwater use controls. On the basis of the exposure pathways analysis (Sections 6 and 7), Site ST-27 is and will continue to be acceptable for continued industrial use provided noninstrusive workers do not come into direct contact with impacted media on a regular basis, and intrusive workers do not engage in excavation activities that disrupt the concrete apron near the source area without appropriate personal protective equipment. It is recommended that access to the site continue to be restricted. This action will prohibit unauthorized site access and unplanned ground disturbance.

The target cleanup objectives also are based on the assumption that future land use will not require extraction of shallow site groundwater for potable uses. Any future lease or new land use of this land must stipulate that shallow groundwater will not be extracted within 1,000 feet of detected dissolved contamination until COPC concentrations have been reduced below applicable concentrations. Excavation in the impacted area also should only be performed by workers who have been briefed on the nature of onsite contamination and trained in proper use of personal protective equipment. These minor restrictions will eliminate potential unprotected exposure of onsite workers to contaminated soil and groundwater at Site ST-27.

10.1.5 Implementation of Long-Term Groundwater Monitoring

Section 10.3 of this CAP provides a complete LTMP for Site ST-27. Long-term groundwater monitoring is being proposed to verify that engineered source reduction technologies and natural chemical attenuation processes are sufficient to achieve the desired degree of remediation (i.e., protect potential receptors). Careful implementation of the LTMP is a key component of this CAP. The proposed remedial alternative for this site calls for groundwater sampling semiannually for 2 years and annually thereafter until SSTLs are attained at every sampling location. Additionally, 2 years of verification sampling will be performed after SSTLs are attained to confirm plume stability. Wells will be purged in accordance with the SAP presented in Appendix I, and then sampled for groundwater COPCs and geochemical indicators of biodegradation.

Groundwater monitoring is recommended to begin in the summer of 1997 upon approval of the final CAP. Results of each groundwater sampling event should be provided to Charleston AFB, SCDHEC, and AFCEE to update all parties involved on remediation progress and to provide new information for pending land use decisions, as necessary.

10.2 IMPLEMENTATION SCHEDULE

Figure 10.2 is a proposed schedule for implementation of the CAP at Site ST-27.

10.3 LONG-TERM MONITORING PLAN

The purpose of the LTMP is to confirm the effectiveness of proposed engineered remediation and natural processes at achieving the desired level of risk reduction in a reasonable timeframe. As part of this monitoring and compliance plan, contaminant behavior in groundwater will be monitored to verify that the proposed corrective action is sufficient to protect groundwater underlying the source area at Site ST-27 and to prevent significant downgradient migration. The plan calls for periodic soil gas sampling to attempt to quantify the VOC removal rates of the SVE and bioventing systems. The plan also calls for the monitoring of LNAPL thickness in monitoring wells during routine monitoring events to ensure LNAPL levels are decreasing over time and not migrating away from the site. In the event that data collected under this program indicate that the selected alternative is insufficient to maintain plume stability and eventually achieve SSTLs at Site ST-27, contingency actions will be implemented to augment the effects of the proposed corrective action.

10.3.1 Monitoring SVE System Performance

The SVE system will be monitored manually on a bi-weekly basis and daily using the ICE's automated measuring and recording devices. The following parameters will be monitored to evaluate the system's ability to extract and treat soil gas:

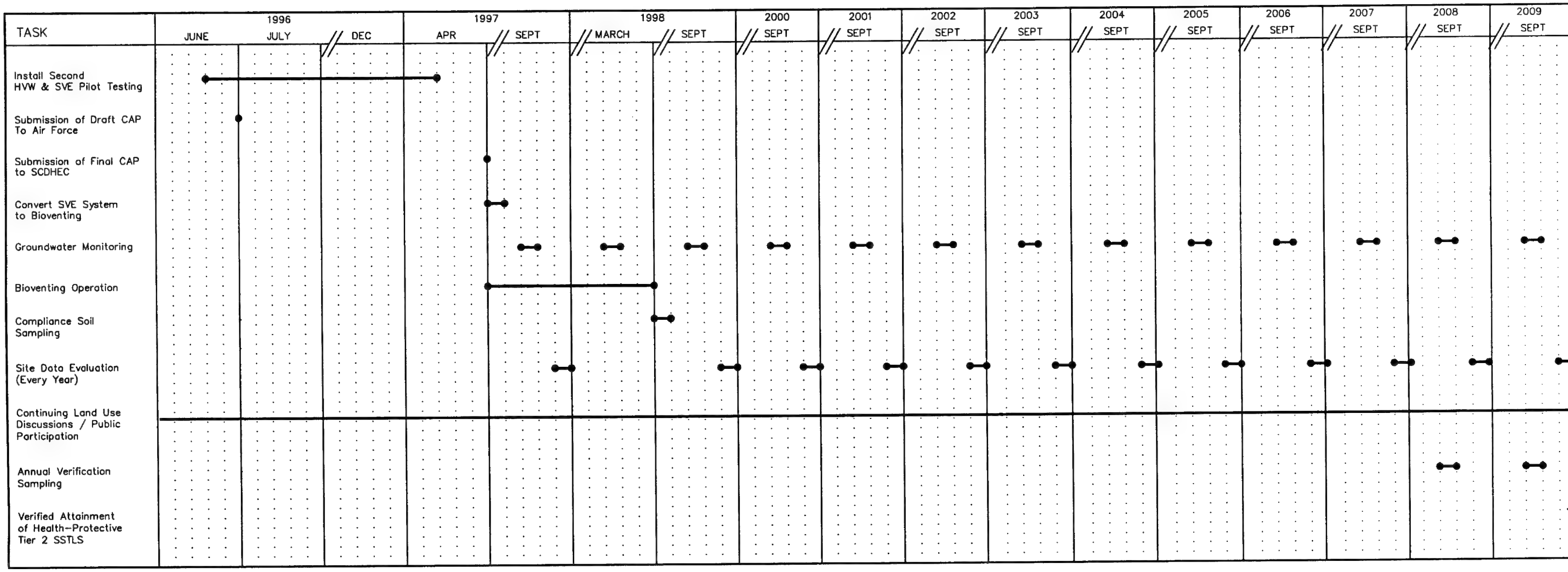
- Extraction flow rates and vacuums at each HVW;
- Soil gas TVH concentrations before and after ICE treatment;
- Vacuum response at the MPs; and
- Soil gas oxygen, carbon dioxide, and TVH concentrations measured in the extracted soil gas and at the MPs.

These monitoring results will be used to determine contaminant removal rates, estimated treatment time, and TVH destruction efficiency.

Soil gas oxygen, carbon dioxide, and TVH concentrations will be measured at the HVWs, in ICE influent and effluent, and at the MPs using a direct-reading Gastech® oxygen/carbon dioxide meter and a Gastech® TVH analyzer. The VR Systems® unit will automatically monitor and record engine coolant, oil, and exhaust temperatures, oil pressure, intake vacuum, flow rate in cubic feet per minute (cfm), carburetor and well valve position (percent open), supplemental fuel usage, duty cycle (efficiency), and engine hours. Vacuum also will be monitored at the MPs using Magnehelic® gauges.

FIGURE 10.2

IMPLEMENTATION OF PROPOSED ACTIONS SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA



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Fixed-based laboratory analytical soil gas samples will be collected from the MPs. Samples will be collected in 1-liter SUMMA® canisters and submitted to the Air Toxics, Ltd. laboratory in Folsom, California for BTEX and TVH analyses using USEPA Method TO-3. These analytical sampling results will be used to determine when the SVE system should be deactivated. Analytical soil gas sampling will be performed after equilibrium TVH soil gas concentrations stabilize at a concentration of 5,000 ppmv or less.

10.3.2 Soil Gas Analytical Sampling

When TVH concentrations in soil gas have dropped to or below 5,000 ppmv, the SVE system will be converted for air injection bioventing to address remaining source area soil contamination. It is critical that soil gas TVH concentrations be well below the LEL of 10,000 ppmv for MOGAS before bioventing air injection begins to ensure that residual vapor concentrations do not pose an explosive hazard. To confirm the remediation of soil gas at Site ST-27, fixed-base laboratory analytical confirmatory sampling will be performed. After field instruments indicate that the desired level of remediation has been attained (i.e., TVH concentrations of about 5,000 ppmv), the SVE system will be shut down and soil gas will be allowed to equilibrate with the surrounding conditions for approximately 30 days. If field instruments indicate the desired equilibrium concentrations have been achieved, confirmatory air samples will be analyzed for TVH concentrations by USEPA Method TO-3, by Air Toxics, Inc. of Folsom, California. If analytical results indicate that soil gas TVH concentrations have decreased below 5,000 ppmv, air injection operations can commence. However, additional air monitoring will be necessary during startup and optimization of the bioventing system to ensure that there is no significant accumulation and/or migration of hydrocarbons vapors that could present unacceptable hazards to potential receptors.

10.3.3 Monitoring Bioventing System Performance

The proposed full-scale injection bioventing system is expected to be installed following 6 months of SVE operations. Once optimization is complete, long-term operation will begin. An operation and maintenance (O&M) manual will be prepared and presented to Charleston AFB personnel prior to the beginning of extended operation. Parsons ES will prepare the manual as part of system installation and optimization. Contents of the O&M plan for bioventing will include system as-built drawings, vendor equipment specifications, maintenance schedules, and a list of emergency contacts.

System checkups should be performed every other week by Charleston AFB personnel. The following activities will typically be performed during a system check:

- Record air injection pressures for each of the injection wells;
- Measure injection blower operating temperature and inlet vacuum;
- Assess the condition of the air inlet filter element and replace as necessary; and
- Note any unusual operating characteristics (e.g., clogged lines or tripped breakers).

All maintenance activities will be recorded on an O&M checklist and will become part of the site record.

In addition to the monitoring described above, *in situ* respiration and radius-of-influence tests will be performed semi-annually at all injection HVWs and MPs at the site. Soil gas samples collected from these locations will be analyzed for BTEX and TVH. This testing and sampling will be used to assess remedial progress and to assure that biodegradation is continuing in accordance with the bioventing technical protocol (Hinchee *et al.*, 1992). If, at the end of 2 years of operation, it appears that the majority of the soil contamination at the site has been biodegraded based on respiration rates and soil gas samples, compliance soil samples will be collected. Samples will be analyzed for all of the soil COPCs using USEPA approved analytical methods. Additional sample collection and analysis details for soil and soil gas are presented in Appendix I, the SAP. Soil samples will be compared to initial samples collected during VW and MP installation and used to determine if contaminant levels have been remediated to Tier 2 SSTLs that are protective of groundwater. Soil gas samples will be used in the same manner. Based on the results of the pilot test performed at Site ST-27, 2 years of operation should be adequate to reduce soil COPCs to concentrations to below SSTLs. When compliance soil sampling results indicate that source soils have been remediated, the system will be deactivated. The bioventing blower will be removed, and the HVWs will be abandoned in place with grout.

10.3.4 Subsurface Soil Compliance Sampling

Six months of SVE followed by 2 years of bioventing are proposed as part of the recommended remedial alternative for Site ST-27. After 2 years of bioventing, approximately 8 subsurface compliance soil samples will be collected within the source area at Site ST-27 to assure that contaminant concentrations and mass have been reduced to soil leaching SSTLs. Samples will be collected from two different depths at four separate boreholes within the source area. Some sampling locations may be moved or excluded as required by utility constraints. Soil sampling locations will be prepared by removing a small concrete core from the proposed borehole location. Samples will then be collected using a Geoprobe® hydraulic push sampler. Soil samples will be collected from the source area smear zone just above the groundwater surface, and from upper saturated soils. Additional soil sampling and analysis information can be found in Appendix I, the SAP.

10.3.5 Groundwater Monitoring

A total of 13 wells will be used to monitor the stability of the dissolved COPC plume at the site over time. The purpose of the monitoring events are to confirm that natural chemical attenuation processes are reducing COPC concentrations and limiting mobility. These wells are located within and surrounding the characterized areal extent of the dissolved COPC plume to ensure that implemented remedial actions and natural chemical attenuation processes are sufficient to eventually attain the most restrictive SSTLs and minimize COPC transport in groundwater. The locations of all wells to be used for LTM are illustrated in Figure 10.1.

Seven existing wells (MW20-7, MW20-14, MW20-15, MW20-17, MW20-19, MW20-20, and MW20-21) are located upgradient from or just outside the influence of

the Site ST-27 contaminant source area, and will be monitored to evaluate background and leading-edge conditions. Six existing wells (MW20-1, MW20-3, MW20-8, MW20-11, MW20-12, and MW20-16), located within the dissolved COPC plume, will be monitored to evaluate the stability of the dissolved COPC plume and possibly the rates of COPC removal as a result of engineered remediation of source soils and natural chemical attenuation.

During routine events, LNAPL thickness measurements will be made to ensure that LNAPL levels are decreasing over time and LNAPL is not migrating away from the initial spill area. In addition, a sample of LNAPL will be collected after two years to determine the actual decrease in BTEX fraction due to the combined effects of SVE/bioventing and natural weathering.

10.3.5.1 Plume Wells

Six existing wells will be used to verify decreasing COPC concentrations and limited downgradient migration of the leading edge of the dissolved contaminant plumes over time. Four wells (MW20-1, MW20-3, MW20-8, and MW20-11) are located within the dissolved plume. MW20-8 is actually a deep well to be sampled to assess vertical contamination. One well (MW20-12) will be sampled primarily to track cis-1,2-DCE, the only non-fuel groundwater COPC. The last plume well (MW20-16) is at the leading edge of the dissolved plume, and will be used to track the extent of plume migration over time. Conservative model simulations predict that benzene may migrate to this well at a concentration of almost 600 μg/L. If COPCs are detected in any of these wells at concentrations greater than those predicted by the fate and transport modeling, the contingency actions described in Section 10.4 would be enacted. These wells will be monitored for parameters listed in Table 10.1. In addition to monitoring the COPCs, all wells will be monitored for vinyl chloride to confirm its presence (or disappearance) at the site.

10.3.5.2 Point-of-Action Wells

Seven existing wells (MW20-7, MW20-14, MW20-15, MW20-17, MW20-19, MW20-20, and MW20-21) will be used as POA wells. The inconsistent groundwater flow directions observed at Site ST-27 necessitate that POA wells encompass the likely changing flow path of the dissolved plume in order to ensure that site-related contaminations do not migrate away from the site at concentrations greater than Tier 1 RBSLs. The POA wells also will be monitored for parameters listed in Table 10.1. Based on an assessment of hydrogeology and natural chemical attenuation processes occurring at the site, it is unlikely that site-related COPCs in excess of even the most stringent Tier 1 target concentrations will ever be measured at the POA wells. The detection of COPC contamination at any of the POA wells will trigger the need to evaluate contingency actions. These actions could include resampling of POA wells to confirm presence of contaminants in excess of the most stringent Tier 1 target concentrations, considering additional corrective actions (e.g., Alternative 3), and/or other actions deemed necessary to ensure that concentrations of site COPCs do not pose an unacceptable risk to potential receptors.

TABLE 10.1

GROUNDWATER MONITORING ANALYTICAL PROTOCOL
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site -Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX)	SW8060 (Gas Chromatography/ Mass Spectrometry method)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	BTEX compounds (benzene, toluene, ethylbenzene, and total xylenes), chlorobenzene, and TMBs have been identified as either groundwater COPCs or compounds that can affect biodegradation of groundwater COPCs	Semiannually for first 2 years and annually thereafter	Collect water samples in a 40 milliliter volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	See Table 2.1	See Table 2.1	Fixed-base
Polycylic aromatic hydrocarbons (PAHs)	SW8270 (Gas Chromatography/ Mass Spectrometry method)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	PAH compound naphthalene has been identified as a groundwater COPC	Semiannually for first 2 years and annually thereafter	Collect water samples in a 1-liter glass container, cool to 4°C	See Table 2.1	See Table 2.1	Fixed-base
Chlorinated aliphatic hydrocarbons (cis-1,2-DCE, vinyl chloride)	SW8260 (Gas Chromatography/Mass Spectrometryt) for volatile organics	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	Cis-1,2-DCE has been identified as a groundwater COPC	Semiannually for first 2 years and annually thereafter	Collect water samples in a 40 milliliter volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	See Table 2.1	See Table 2.1	Fixed-base
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis)	Every year	Collect water samples in a 40 milliliter volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	See Table 2.1	See Table 2.1	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions: can be used as an indicator of the terminal electron acceptor process involved in COPC biodegradation	Every year	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution	NA[a]	0.0 pe units	Field

TABLE 10.1 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade COPCs	Semiannually for first 2 years and annually thereafter	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution	NA	0.5 mg/L	Field
Manganese (Mn^{+2})	Colorimetric HACH 8034	Field only	Elevated concentrations of reduced forms of manganese indicate that microorganisms are facilitating manganese reduction to biodegrade COPCs	Every year	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.05 mg/L	Field
Ferrous iron (Fe^{2+})	Colorimetric HACH 8146	Field only	Elevated ferrous iron concentrations indicate that microorganisms are facilitating ferric iron reduction to biodegrade COPCs	Every year	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.024 mg/L	Field
Sulfate (SO_4^{2-})	Colorimetric HACH 8051	Field only	Reduced concentrations of sulfate indicate that microorganisms are facilitating sulfate reduction to biodegrade COPCs	Every year	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	0.01 mg/L	0.01 mg/L	Field
Sulfide (S^{-2})	Colorimetric HACH 8131	Field only	Elevated concentrations of sulfide forms indicate that microorganisms are facilitating sulfate reduction to biodegrade COPCs	Every year	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	NA	NA	Field

TABLE 10.1 (Continued)

GROUNDWATER MONITORING ANALYTICAL PROTOCOL
CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST-27, CHARLESTON AFB, SOUTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Every year	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards	NA	0.00 pH units	Field
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Semiannually for first 2 years and annually thereafter	Measure directly using a contained flow-through cell with probe portals	NA	1.0 °C	Field
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Semiannually for first 2 years and annually thereafter	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated	NA	0.02 µmhos/cm	Field
Alkalinity (as $CaCO_3$)	Colorimetric HACH 8221	Field only	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Semiannually for first 2 years and annually thereafter	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis.	NA	20.0 mg/L	Field

NA = not applicable

10.3.5.3 Sampling Frequency

Each of the groundwater sampling points will be sampled semiannually for 2 years and annually thereafter until COPC concentrations decrease below proposed SSTLs, in approximately 11 years. (i.e., by the year 2007, which would require 12 sampling events from 1997 to 2007) Sampling results will be evaluated after each event to document reduction of contaminant concentrations and plume stability. Monitoring of all 13 wells in the LTM network will continue until the site has uniformly attained the SSTLs for groundwater. Two years of annual sampling will be performed following attainment of the SSTLs to ensure continuing compliance with the approved target concentrations (i.e., planned for 2008 and 2009).

10.4 CONTINGENCY PLAN

Should engineered remediation and natural chemical attenuation processes fail to achieve and maintain SSTLs and retard plume migration, there should be no significant impact on the land use plans for the site. No nonindustrial land use has been proposed for Site ST-27; for the foreseeable future, Site ST-27 will continue to be used as a maintenance and fueling area. If SSTLs are not achieved at Site ST-27, exposure controls may have to be maintained to prevent onsite workers from coming into direct contract with impacted media. Nonetheless, even if the most stringent SSTLs are not met at Site ST-27, the site will still be suitable for nonintrusive activities.

Groundwater extraction is not anticipated at the site so long as alternate water supplies exist. In the unlikely event that shallow groundwater from the site must be extracted for potable uses, and applicable Tier 1 RBSLs for groundwater have not yet been achieved, the following contingency actions are available:

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6.
- If onsite groundwater is to be used for potable uses before natural attenuation processes can achieve Tier 1 RBSLs, more active methods of remediation will be evaluated. These could include possible initiation of more aggressive groundwater treatment methods (e.g., Alternative 3).

Once again, failure of the proposed soil remediation and ongoing natural chemical attenuation to achieve risk-based SSTLs will not impact the current or proposed uses of Site ST-27, unless groundwater must be extracted for long-term potable uses or saturated soils must be excavated (without appropriate personal protective equipment) before the appropriate SSTLs have been met. Because low groundwater velocity at the site, multidirectional flow, and natural chemical attenuation processes have been shown to be effective in minimizing migration, no detectable levels of COPCs are expected to migrate to within approximately 50 feet upgradient from the POA wells. If COPCs are detected in any of the POA wells, the following contingency actions are available:

- All wells will be sampled to determine the extent of plume migration and to locate the highest plume concentrations.

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6.
- Risks associated with slower rates of natural chemical attenuation will be evaluated.
- If significant risk exists, more active methods of remediation, such as Alternative 3 (Section 9), will be evaluated.

10.5 COST OF IMPLEMENTATION

A summary of the estimated present-worth cost of implementing the recommended remedial alternative is provided in Section 9.3.2.3. Table 10.2 provides a cost estimate, based on estimated expenditures during the next 5 fiscal years, to assist the Air Force in budgeting for implementation of the recommended Site ST-27 corrective actions. The present worth of implementing Alternative 2 to uniformly attain and verify SSTLs is $303,349. It is estimated that it will take about 11 years to attain SSTLs in all affected media under Alternative 2. Verification of continuing compliance will require an additional 2 years, for a total projected compliance timeframe of 13 years (i.e., 1996 until 2009). In contrast, it is estimated that it would take more than 28 years (i.e., the year 2024) to attain Tier 1 RBSLs under Alternative 2. The added cost of additional monitoring and site management required to document attainment of Tier 1 RBSLs would increase the estimated present worth cost to $354,530.

TABLE 10.2
ALTERNATIVE 2 IMPLEMENTATION
ESTIMATED COST BY FISCAL YEAR [a/]
SITE ST-27 CORRECTIVE ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CHARLESTON AFB, SOUTH CAROLINA

Task	FY97	FY98	FY99	FY00	FY01
Short-Term SVE Operation	$16,896 [b/]				
Confirmatory Soil Gas Sampling		$6,164 [b/]			
Installation of Bioventing System		$17,776 [b/]			
Confirmatory Soil Sampling			$17,370 [b/]		
Operation and Maintenance of Bioventing System		$10,139 [b/]	$10,848 [b/]		
Groundwater Sampling in Accordance with LTMP		$16,135 [b/]	$34,529	$19,846	$21,298
Site Management	$9,600	$10,272	$10,991	$11,760	$12,583
FISCAL YEAR TOTALS	**$26,496**	**$60,486**	**$73,738**	**$31,606**	**$33,881**

a/ Assumes a 7 percent annual inflation rate (USEPA, 1993).
b/ Currently funded under Parsons ES contract with AFCEE.

SECTION 11

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APPENDIX H

REVISED ALTERNATIVE COST ESTIMATES

RISK-BASED APPROACH TO REMEDIATION

ST-27, CHARLESTON AFB, SOUTH CAROLINA

Alternative 1 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: JAP
Date: 8/21/97
Checked by: SLC
Date: 8/21/97

Capital Costs

Short-Term SVE Operation

Supplemental Propane	6 months x	$700	/month	$4,200
Effluent Samples (2 samples @ $140 ea per month)	6 months x	$280	/month	$1,680
Sampling Labor (8 hours/month @ 60$/hour)	6 months x	$480	/month	$2,880
Condensate Disposal	6 months x	$200	/month	$1,200
ICE System Maintenance	6 months x	$900	/month	$5,400
Contingency (10%)		$1,536	lump sum	$1,536
			Subtotal	$16,896

Confirmatory Soil Gas Sampling at 13 Locations

Soil Gas Analysis (EPA TO-3)	10 samples x	$130	/sample	$1,300
Sampling Labor	32 hours x	$60	/hour	$1,920
Sample Shipping		$250	lump sum	$250
Per Diem	4 days x	$96	/day	$384
Travel		$1,500	lump sum	$1,500
Equipment Rental		$250	lump sum	$250
Contingency (10%)		$560	lump sum	$560
			Subtotal	$6,164
			Total Capital Cost	$23,060

Alternative 1 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Annual Costs

Groundwater Sampling

Sampling Labor 13 Long-Term Monitoring Wells 3 QA/QC 16 Total Samples	100 hours x	$60	/hour	$6,000
Analytical Subcontractor				
	16 SW 8260 x	$150	/each	$2,400
	16 Naphthalene x	$200	/each	$3,200
Supplies		$500	lump sum	$500
Travel		$1,500	lump sum	$1,500
Per Diem	8 days x	$96	day	$768
Office ODC		$300	lump sum	$300
Contingency (10%)		$1,467	lump sum	$1,467
			Subtotal per event	$16,135
Site Management	160 hrs/yr x	$60	/hour	$9,600

Summary of Costs

Total Capital Costs $23,060

Annual Costs

Frequency:

1 & 2 years	2x/y	$32,270
3-20 years	1x/y	$16,135

Alternative 1 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Groundwater Sampling twice the first two years,
annually for the following 18 years

yrs 1 & 2	P/A i=7%, n=2	PWF = 1.8017	
		Present Worth Cost	$58,140
yrs 3-20	P/A i=7%, n=20	PWF = 10.391	
minus 2 yrs	P/A i=7%, n=2	PWF = 1.8017	
		Present Worth Cost	$138,587
	two years confirmation sampling		
	P/F i=7%, n=21	PWF = 0.24151	
		Present Worth Cost	$3,897
	P/F i=7%, n=22	PWF = 0.22571	
		Present Worth Cost	$3,642
	Groundwater sampling Present Worth Cost		$204,265

Site Management every year

	P/A i=7% n=22	PWF = 11.061	
		Present Worth Cost	$106,186

Total Present Worth of Alternative 1 = $333,511

Alternative 2 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Capital Costs

Short-Term SVE System Operation and Maintenance (From Alternative 1)				$16,896
Confirmatory Soil Gas Sampling (From Alternative 1)				$6,164
Installation of the Bioventing System				
Design/Procure/Install	120 hours x	$60	/hour	$7,200
Blower/Shed/Misc Piping		$2,000	lump sum	$2,000
Conc. Cutting/ Piping Installation		$2,500	lump sum	$2,500
Electrical Subcontractor		$1,500	lump sum	$1,500
Per Diem	10 days x	$96	/day	$960
Travel		$1,500	lump sum	$1,500
Equipment Rental		$500	lump sum	$500
Contingency (10%)		$1,616	lump sum	$1,616
			Subtotal	$17,776
			Total Capital Cost	$40,836

Future Costs

Confirmatory Soil Sampling				
Sampling Labor 8 Soil Samples 1 QA/QC 9 Total Samples	80 hours x	$60	/hour	$4,800
Analytical Subcontractor				
	9 BTEX x	$85	/each	$765
	9 Naphthalene x	$240	/each	$2,160

Alternative 2 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: HAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Concrete Coring	4 holes x	$250	/each	$1,000
Geoprobe Rental	4 days x	$500	/day	$2,000
Supplies		$500	lump sum	$500
Travel		$1,500	lump sum	$1,500
Per Diem	8 days x	$96	day	$768
Office ODC		$300	lump sum	$300
Contingency (10%)		$1,379	lump sum	$1,379
		Total Future Cost		$15,172

Annual & Operational Costs

Groundwater Sampling (From Alternative 1)			yrs 1 & 2	$32,270
			yrs 3-10	$16,135
Site Management (From Alternative 1)				$9,600
Operation and Maintenance of the Bioventing System				
System Monitoring				
Monitoring Labor	100 hours x	$60	/hour	$6,000
Travel		$1,500	lump sum	$1,500
Per Diem	4 days x	$96	/day	$384
Equipment Rental		$1,200	lump sum	$1,200

Electrical Usage
1 hp x 745.7 watts/hpr= 746 watts
746 watts = .746 kilowatts
.746 kilowatts x 365 days x 24 hrs/day = 6,535 kw
6,535 kw x $0.06/kw = $392

$392
Annual O&M Cost $9,476

Alternative 2 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAR
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Summary of Costs

			Total Capital Cost	$40,836
Future Costs				
Soil Samping in Source Area in 2 Years				
		P/F i=7%, n=2	PWF = 0.87344	
			Present Worth Cost	$13,252
Annual & Operational Costs				
Groundwater Sampling twice during the first two years, annually the following eight years				
	yrs 1 & 2	from A-1	Present Worth Cost	$58,142
	yrs 3-10	P/A i=7%, n=10	PWF = 6.94	
	minus 2 yrs	P/A i=7%, n=2	PWF = 1.8017	
			Present Worth Cost	$82,906
		two years confirmation sampling		
		P/F i=7%, n=11	PWF = 0.47509	
			Present Worth Cost	$7,666
		P/F i=7%, n=12	PWF = 0.44401	
			Present Worth Cost	$7,164
		Groundwater Sampling Present Worth Cost		$155,879
Site Management Every Year				
		P/A i=7% n=12	PWF= 7.9426	
			Present Worth Cost	$76,249
Bioventing System O&M				
		P/A i=7%, n=2	PWF = 1.808	
			Present Worth Cost	$17,133

Total Present Worth of Alternative 2 = $303,349

Alternative 3 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Capital Costs

Short-Term SVE System Operation and Maintenance (From Alternative 1)	$16,896
Confirmatory Soil Gas Sampling (From Alternative 1)	$6,164
Design and Intallation of the Biosparging System (See Attached Cost Sheet)	$331,000
Total Capital Cost	$354,060

Future Costs

Confirmatory Soil Sampling

Sampling Labor 16 Soil Samples 2 QA/QC 18 Total Samples	160 hours x	$60	/hour	$9,600
Analytical Subcontractor				
	18 BTEX x	$85	/each	$1,530
	18 Naphthalene x	$240	/each	$4,320
Concrete Coring	8 holes x	$250	/each	$2,000
Geoprobe Rental	6 days x	$500	/day	$3,000
Supplies		$500	lump sum	$500
Travel		$1,500	lump sum	$1,500
Per Diem	12 days x	$96	day	$1,152
Office ODC		$300	lump sum	$300
Contingency (10%)		$2,390	lump sum	$2,390
		Total Future Cost		$26,292

Alternative 3 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: WAP
Date: 8/14/94
Checked by: SCC
Date: 8/21/97

Annual & Operational Costs

Annual Groundwater Sampling (From Alternative 1)			yrs 1 & 2	$32,270
			yrs 3-11	$16,135
Site Management (From Alternative 1)				$9,600
Operation and Maintenance of the Biosparging/SVE System				
System Monitoring				
5 hours/week x 52 weeks/year =	260 hours x		$60 /hour	$15,600
Electrical Usage				
25 hp x 745.7 watts/hp=	18650 watts			
18650 watts = 18.65 kilowatts				
18.65 kilowatts x 365 days x 24 hrs/day =		163,374 kw		
x $0.06/kw			$9,802	$9,802
			Annual O&M Cost	$25,402

Summary of Costs

			Total Capital Cost	$354,060
Future Costs				
Soil Samping in Source Area in 3 years				
	P/F i=7%, n=3	PWF =	0.8163	
			Present Worth Cost	$21,462
Annual & Operational Costs				
Groundwater Sampling twice the first two years, annually for the following 9 years				
yrs 1 & 2	from A-1		Present Worth Cost	$58,142
yrs 3-11	P/A i=7% n=11	PWF =	7.4058	
minus 2 yrs	P/A i=7% n=2	PWF =	1.8017	
			Present Worth Cost	$90,423

Alternative 3 Cost Estimate
Charleston AFB - Site ST-27
725526.04000

Author: NAP
Date: 8/14/97
Checked by: SLC
Date: 8/21/97

Site Management

P/A i=7% n=11	PWF =	7.4986		
	Present Worth Cost		$71,987	

System O&M

P/A i=7%, n=3	PWF =	2.6243	
	Present Worth Cost		$66,664

Total Present Worth of Alternative 3 = $662,738

TABLE A.12

1996 ANALYTICAL DATA

LABORATORY REPORT

RISK-BASED APPROACH TO REMEDIATION

ST-27, CHARLESTON AFB, SOUTH CAROLINA

Evergreen
Analytical
Laboratory

January 23, 1996

MR DOUG DOWNEY
PARSONS ENGINEERING SCIENCE INC
1700 BROADWAY SUITE 900
DENVER, CO 80290

Data Report : 96-0089
Client Project : CHARLESTON AFB
ST-27

Dear Mr. Downey:

Enclosed are the analytical results for the samples shown in the Sample Log Sheet. The enclosed data have been reviewed for quality assurance. If you have any questions concerning the reported information, please contact Patty McClellan, Program Manager, or me.

Please Note: Samples marked for return on the Sample Log Sheet are considered hazardous, unsuitable for municipal disposal or were placed on hold at your request. Samples considered hazardous or unsuitable for municipal disposal will be returned to you immediately. Samples placed on <u>hold</u> will be returned and samples <u>not</u> considered hazardous will be disposed of one (1) month from the date of this letter.

The invoice for this work will be mailed to your Accounts Payable department shortly.

Thank you for using the services of Evergreen Analytical.

Sincerely,

PMcClellan for

Jack Barney
President

TM

Evergreen Analytical Sample Log Sheet

Project # 96-0089

Date(s) Sampled: 01/10,11/96 COC

Date Due: 01/19/96-UST
01/26/95-OTHERS

Date Received: 01/12/96 0930

Holding Time(s): 1/24-VOA,1/25-BTEX, TVH,TEH

Client Project I.D. CHARLSTON AFB, ST-27

Rush STANDARD

Client: PARSONS ENGINEERING SCIENCE, INC.

Address: 1700 BROADWAY SUITE 900
DENVER, CO 80290

Contact: DOUG DOWNEY

Phone #831-8100 **Fax #**831-8208*

Cooler Return N/A

E.A. Cooler # 7

Airbill # FEDEX 7059252524

Client P.O. 725526.006

Special Invoicing/Billing

Special Instructions SEND A COPY OF THE RESULTS TO: GRANT WATKINS; PARSONS ES; 401 HARRISON OAKS BLVD., CARY NC, 27513; PHONE 919-677-0080;*FAX 919-677-0118 REPORT SOILS ON A DRY WEIGHT BASIS.

Lab ID #	Client ID#	Analysis	Mtx	Btl	Loc
X17782A/B	MW20-2	VOA 8260	W	40V	9
X17783A/B	MW20-4	VOA 8260	W	40V	9
X17784A/B	MW20-12	VOA 8260	W	40V	9
X17786A	TRIP BLANK	VOA 8260	W	40V	9
X17785A/B	COMP-1	BTEX,TVH(% MOISTURE)	S	2WM	2
X17785C	COMP-1	TEH JET-A	S	2WM	2
X17785D-G	COMP-1	FLASHPOINT	S	2WM	CL4
X17785H	COMP-1	REACTIVITY	S	2WM	CL4
X17785I	COMP-1	CORROSIVITY	S	2WM	CL4
X17785J/K	COMP-1	TOTAL PHENOLS	S	2WM	CL4

R=Sample to be returned

Route To GC/MS X GC X Metals __ Wet Chem X HPLC __ SxPrep X

SxRec C QA/QC C Acctg C File Orig

Page 1 of 1 Page(s)

Custodian/Date: RB 1/12/96

Am 1/16/96

pu 1/12/96

CHAIN OF CUSTODY RECORD / ANALYTICAL SERVICES REQUEST

Page 1 of 1

Evergreen Analytical Inc.
4036 Youngfield St.
Wheat Ridge, Colorado 80033
(303) 425-6021
FAX (303) 425-6854
(800) 845-7400

COMPANY Parsons Engineering Science
ADDRESS 1700 Broadway, Ste. 900
CITY Denver STATE CO ZIP 80290
PHONE# (303) 831-8100 FAX # (803) 831-8205 FAX RESULTS (Y) / N

CLIENT CONTACT (print) Doug Downey
PROJECT I.D. Charleston AFB, ST-27
EAL. QUOTE # ____ P.O.# 725526.006
TURNAROUND REQUIRED* ☐ STD (2 wks) ☐ STD UST (3 day) ☒ Other (Specify) AFCEE
*expedited turnaround subject to additional fee

Sampler Name:
(signature) Grant Watkins
(print) Grant Watkins
Evergreen Analytical Cooler No. #7
Cooler Received ____

Please **PRINT** all information:

EAL use only
Do not write in shaded area
EAL Project # 0089
Custodian PRB

CLIENT SAMPLE IDENTIFICATION	DATE SAMPLED	TIME	No. of Containers	Water-Drinking/Discharge/Ground (circle)	Soil / Solid	Oil / Sludge	TCLP VOA/BNA/Pest/Herb/Metals (circle)	VOA 8260/524/524.2 (circle) 8260	BNA 8270/625 (circle)	Pesticides 8080/608 (circle)	Pest/PCBs 8080/608/508 (circle)	Herbicides 8150/515 (circle)	PCB Screen	BTEX 8020/602 (circle)/MTBE (circle)	TRPH 418.1/Oil & Grease 413.1 (circle)	TVPH 801smod. (Gasoline)	TEPH 8015mod. (Diesel) Jet Fuel	Total Metals-DW / NPDES / SW846 (circle & list metals below)	Dissolved Metals - DW / SW846 (circle & list metals below)	Flashpoint	Reactivity	Corrosivity	Phenols (420.1)	EAL Sample No.
MW20-2	1-10-96	12:30	2	X				X																X17782A/B
MW20-4	1-10-96	12:55	2	X				X																783
MW20-12	1-10-96	13:20	2	X				X																784
COMP-1	1-11-96	13:25	11		X									X		X	X			X	X	X	X	785A-K
TRIP BLANK																								786A
														A		B	C			D-G	H	I	J/K	

HT:
Location CL3, 9
DD: Analyze trip blank 8260 per Leigh Benson 1/15/96 pm
Container Size 40, 2w

Instructions: For TEPH (Jet Fuel): use JP-4 Jet Fuel Standard
Send Copy of Results To: Grant Watkins, Parsons ES, 401 Harrison Oaks Blvd, Cary, NC 27513
FAX: (919) 677-2118 P: (919) 677-4050

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Date/Time	Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Date/Time
				Grant Watkins	1-11-96	[illegible]	1/12/96

Evergreen Analytical Sample Receipt/Check-in Record

Date & Time Rec'd: 1/12/96 0930 Shipped Via: FEDEX 7059252521
(Airbill # if applicable)

Client : Parsons E. S.

Client Project ID(s): Charlston AFB, ST-27

EAL Project #(s): 96- 0089 EAL Cooler(s): Y N

Cooler#	100									
Ice packs	Y	N	Y	N	Y	N	Y	N	Y	N
Temperature °C	9									

	Y	N	N/A
1. Custody seal(s) present:	✓		
Seals on cooler intact	✓		
Seals on bottle intact			✓
2. Chain of Custody present:	✓		
3. Samples Radioactive: (Comment on COC if >0.5mr/h)		✓	
4. Containers broken or leaking: (Comment on COC if Y)		✓	
5. Containers labeled:	✓		
6. COC agrees w/ bottles received: (Comment on COC if N)	✓		
7. COC agrees w/ labels: (Comment on COC if N)	✓		
8. Headspace in vials-waters only: (Comment on COC if Y)		✓	
9. VOA samples preserved:	✓		
10. pH measured on metals, cyanide or phenolics*:			✓

List discrepancies ______

*Non-EAL provided containers only, water samples only.

	Y	N
11. Metal samples present:		✓
Total ____, Dissolved ____, TCLP ____		
D or PD to be filtered:		
T,TR,D,PD to be Preserved:		
12. Short holding times:		✓
Specify parameters ______		
13. Multi-phase sample(s) present:		✓
14. COC signed w/ date/time:	✓	

Comments: ______

(Additional comments on back)

Custodian Signature/Date: RB Black 1/12/96

CHAIN OF CUSTODY RECORD / ANALYTICAL SERVICES REQUEST

Page 1 of 1

Evergreen Analytical Inc.
4036 Youngfield St.
Wheat Ridge, Colorado 80033
(303) 425-6021
FAX (303) 425-6854
(800) 845-7400

COMPANY Parsons Engineering Science
ADDRESS 1700 Broadway, Ste. 900
CITY Denver STATE CO ZIP 80290
PHONE# (303) 831-8100 FAX # (803) 831-8208 FAX RESULTS Y / N

CLIENT CONTACT (print) Doug Downey
PROJECT I.D. Charleston AFB, ST-27
EAL. QUOTE # ____ P.O.# 725526.006
TURNAROUND REQUIRED* ☐ STD (2 wks) ☐ STD UST (3 day) ☒ Other (Specify) AFCEE
*expedited turnaround subject to additional fee

Sampler Name:
(signature) Grant Watkins
(print) Grant Watkins
Evergreen Analytical Cooler No. #7
Cooler Received ____

Please **PRINT** all information:

EAL use only
Do not write in shaded area
EAL
Project # ____
Custodian ____

CLIENT SAMPLE IDENTIFICATION	DATE SAMPLED	TIME	No. of Containers	MATRIX: Water-Drinking/Discharge/Ground (circle)	MATRIX: Soil / Solid	MATRIX: Oil / Sludge	TCLP VOA/BNA/Pest/Herb/Metals (circle)	VOA 8260/624/524.2 (circle) 8260	BNA 8270/625 (circle)	Pesticides 8080/608 (circle)	Pest/PCBs 8080/608/508 (circle)	Herbicides 8150/515 (circle)	PCB Screen	BTEX 8020/602 (circle)/MTBE (circle)	TRPH 418.1/Oil & Grease 413.1 (circle)	TVPH 8015mod. (Gasoline)	TEPH 8015mod. ~~(Diesel)~~ Jet Fuel	Total Metals-DW / NPDES / SW846 (circle & list metals below)	Dissolved Metals - DW / SW846 (circle & list metals below)	Flashpoint	Reactivity	Corrosivity	Phenols (420.1)	EAL Sample No.
MW20-2	1-10-96	12:30	2	X				X																
MW20-4	1-10-96	12:55	2	X				X																
MW20-12	1-10-96	13:20	2	X				X																
COMP-1	1-11-96	13:25	11		X									X		X	X			X	X	X	X	

HT:
DD:
Location
Container Size

Instructions: For TEPH (Jet Fuel): use JP-4 Jet Fuel Standard Trip blank rec'd [initials] 1/12/96
Send Copy of Results To: Grant Watkins, Parsons ES, 401 Harrison Oaks Blvd, Cary, NC 27513
FAX: (919) 677-0118 P: (919) 677-9880

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Date/Time	Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Date/Time
				Grant Watkins	1-11-96	[illegible signature]	1/12/96

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA
METHOD BLANK REPORT

Method Blank Number	: RB011296	Client I.D.	: CHARLESTON AFB, ST-27
Date Extracted/Prepared	: 01/12/96	Lab Project No.	: 96-0089
Date Analyzed	: 01/12/96	Effective Dilution	: 1.00
		Method	: 8260A
		Lab File No.	: >V9435

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Chloromethane	74-87-3	U	10
Bromomethane	74-83-9	U	10
Vinyl Chloride	75-01-4	U	10
Chloroethane	75-00-3	~~U~~	10
Methylene Chloride	75-09-2	U	5
Acetone	67-64-1	U	100
Carbon Disulfide	75-15-0	U	5
1,1-Dichloroethene	75-35-4	U	5
1,1-Dichloroethane	75-34-3	U	5
Trans 1,2-Dichloroethene	156-60-5	U	5
Cis 1,2-Dichloroethene	156-59-2	U	5
Chloroform	67-66-3	U	5
1,2-Dichloroethane	107-06-2	U	5
2-Butanone	78-93-3	U	100
1,1,1-Trichloroethane	71-55-6	U	5
Carbon Tetrachloride	56-23-5	U	5
Bromodichloromethane	75-27-4	U	5
Vinyl Acetate	108-05-4	U	50
1,2-Dichloropropane	78-87-5	U	5
Trans-1,3-Dichloropropene	10061-02-6	U	5
Trichloroethene	79-01-6	U	5
1,1,2-Trichloroethane	79-00-5	U	5
Benzene	71-43-2	U	5
Dibromochloromethane	124-48-1	U	5
Cis-1,3-Dichloropropene	10061-01-5	U	5
2-Chloroethylvinyl Ether	110-75-8	U	10
Bromoform	75-25-2	U	5
4-Methyl-2-Pentanone	108-10-1	U	50
2-Hexanone	591-78-6	U	50
1,1,2,2-Tetrachloroethane	79-34-5	U	5
Tetrachloroethene	127-18-4	U	5
Toluene	108-88-3	U	5
Chlorobenzene	108-90-7	U	5
Ethyl Benzene	100-41-4	U	5
Styrene	100-42-5	U	5
Total Xylenes	1330-20-7	U	5

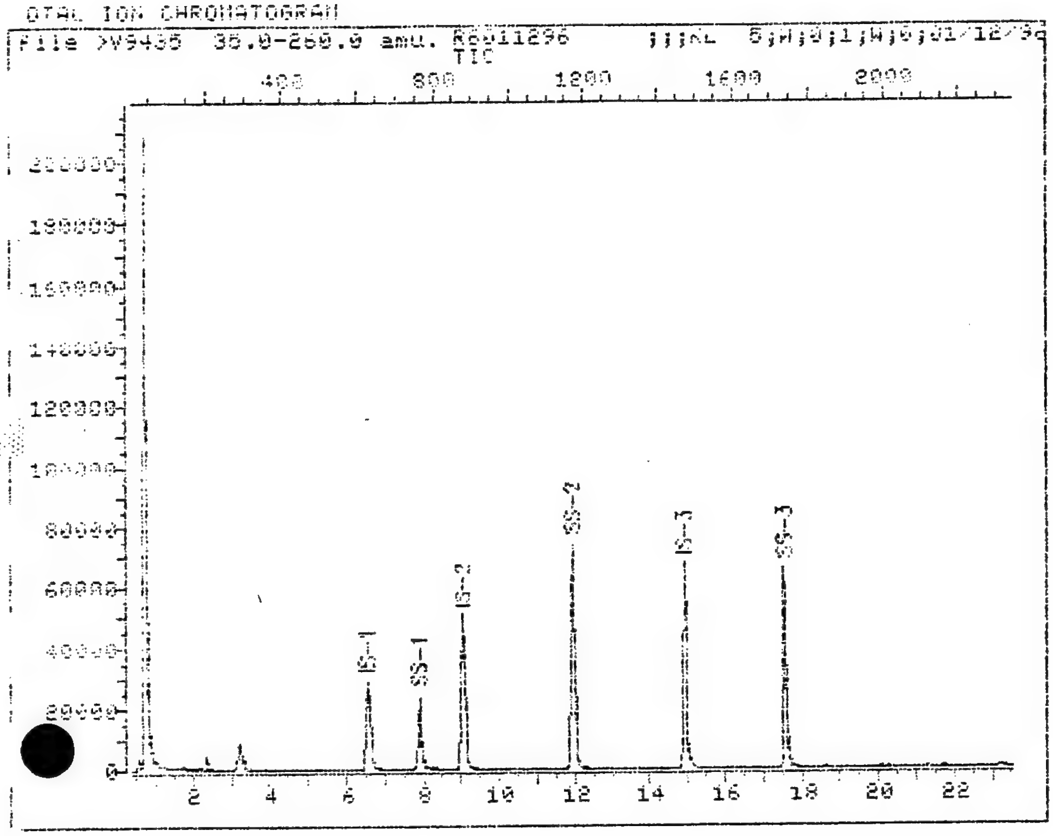
Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	98%	(90-109)
Toluene-d8	101%	(92-108)
Bromofluorobenzene	99%	(87-115)

Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pa. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.
Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

OTAL ION CHROMATOGRAM



Data File: >V9435::V4
Name: R8011296 ;;;KL
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^V9435::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14 Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 10:53
Injected at: 960112 10:28

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA
METHOD BLANK REPORT

Method Blank Number	: RB011596	Client I.D.	: CHARLESTON AFB, ST-27
Date Extracted/Prepared	: 01/15/96	Lab Project No.	: 96-0089
Date Analyzed	: 01/15/96	Effective Dilution	: 1.00
		Method	: 8260A
		Lab File No.	: >V9460

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Benzene	71-43-2	U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	96%	(90-109)
Toluene-d8	98%	(92-108)
Bromofluorobenzene	97%	(87-115)

Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
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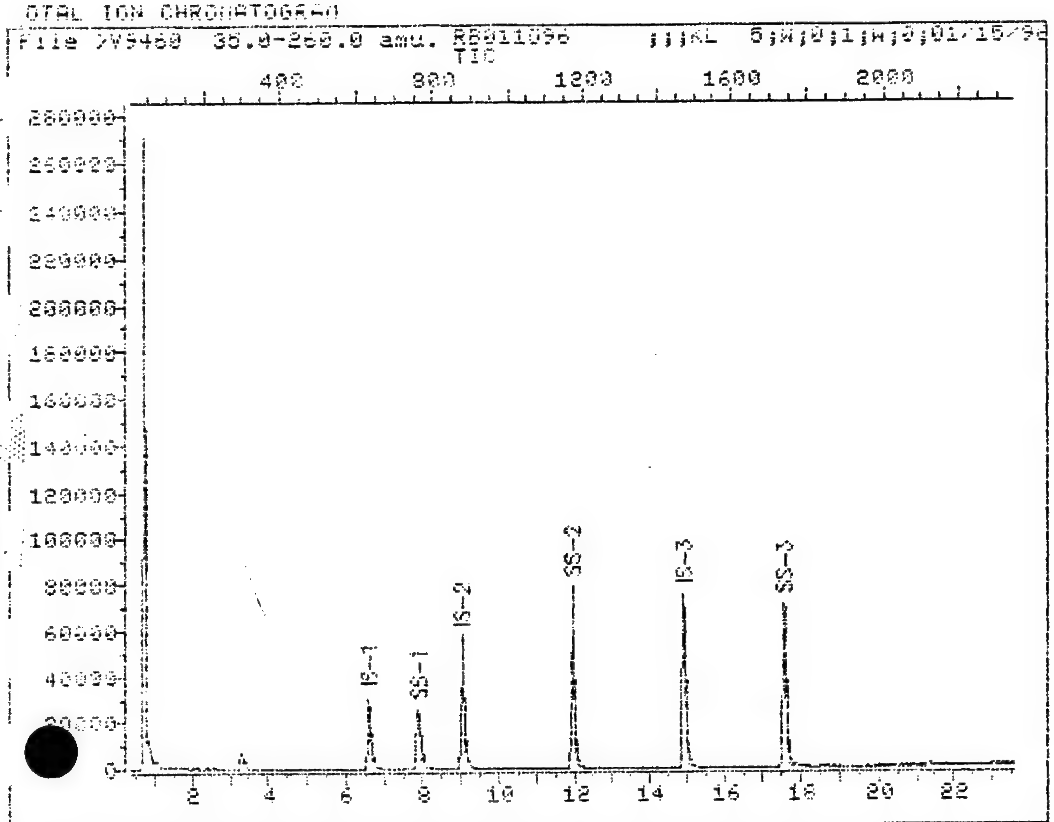
Analyst

Approved

OTAL ION CHROMATOGRAM



Data File: >U9460::U4
Name: RB011596 ;;;KL
Misc: 5;W;0;1;W;0;01/15/96;0

Quant Output File: ^U9460::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14 Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960115 13:29
Injected at: 960115 13:05

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA
METHOD BLANK REPORT

Method Blank Number	: RB011896	Client I.D.	: CHARLESTON AFB, ST-27
Date Extracted/Prepared	: 01/18/96	Lab Project No.	: 96-0089
Date Analyzed	: 01/18/96	Effective Dilution	: 1.00
		Method	: 8260A
		Lab File No.	: >V9506

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Chloromethane	74-87-3	U	10
Bromomethane	74-83-9	U	10
Vinyl Chloride	75-01-4	U	10
Chloroethane	75-00-3	U	10
Methylene Chloride	75-09-2	U	5
Acetone	67-64-1	U	100
Carbon Disulfide	75-15-0	U	5
1,1-Dichloroethene	75-35-4	U	5
1,1-Dichloroethane	75-34-3	U	5
Trans 1,2-Dichloroethene	156-60-5	U	5
Cis 1,2-Dichloroethene	156-59-2	U	5
Chloroform	67-66-3	U	5
1,2-Dichloroethane	107-06-2	U	5
2-Butanone	78-93-3	U	100
1,1,1-Trichloroethane	71-55-6	U	5
Carbon Tetrachloride	56-23-5	U	5
Bromodichloromethane	75-27-4	U	5
Vinyl Acetate	108-05-4	U	50
1,2-Dichloropropane	78-87-5	U	5
Trans-1,3-Dichloropropene	10061-02-6	U	5
Trichloroethene	79-01-6	U	5
1,1,2-Trichloroethane	79-00-5	U	5
Benzene	71-43-2	U	5
Dibromochloromethane	124-48-1	U	5
Cis-1,3-Dichloropropene	10061-01-5	U	5
2-Chloroethylvinyl Ether	110-75-8	U	10
Bromoform	75-25-2	U	5
4-Methyl-2-Pentanone	108-10-1	U	50
2-Hexanone	591-78-6	U	50
1,1,2,2-Tetrachloroethane	79-34-5	U	5
Tetrachloroethene	127-18-4	U	5
Toluene	108-88-3	U	5
Chlorobenzene	108-90-7	U	5
Ethyl Benzene	100-41-4	U	5
Styrene	100-42-5	U	5
Total Xylenes	1330-20-7	U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	100%	(90-109)
Toluene-d8	101%	(92-108)
Bromofluorobenzene	97%	(87-115)

Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
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E = Compound is detected at a concentration outside the calibration limits.
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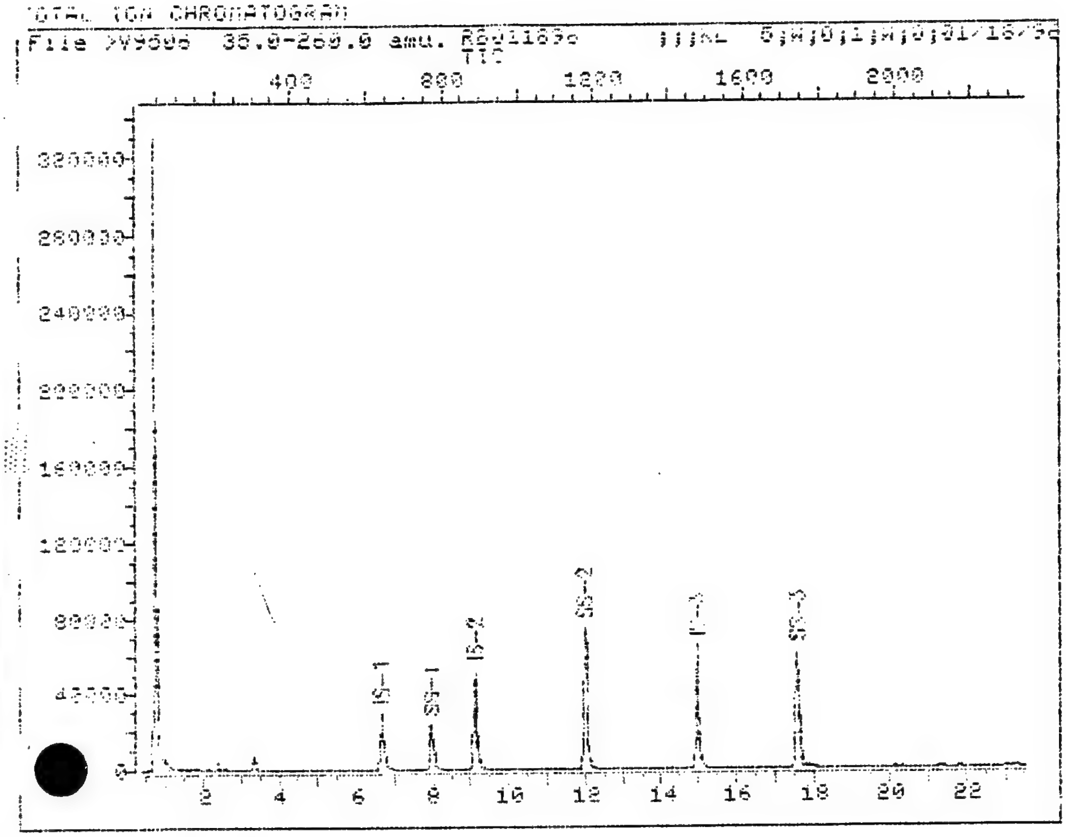
Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9506::V4
Name: RB011896 ;;;KL
Misc: 5;W;0;1;W;0;01/18/96;0

Quant Output File: ^V9506::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14 Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960118 10:38
Injected at: 960118 10:13

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: MW20-2	Client I.D.	: CHARLESTON AFB, ST-27
Lab Sample Number	: X17782	Lab Project No.	: 96-0089
Date Sampled	: 01/10/96	Effective Dilution	: 1.00
Date Received	: 01/12/96	Method	: 8260A
Date Extracted/Prepared	: 01/12/96	Matrix	: WATER
Date Analyzed	: 01/12/96	Lab File No.	: >V9445
		Method Blank No.	: RB011296

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Chloromethane	74-87-3	1	J	10
Bromomethane	74-83-9		U	10
Vinyl Chloride	75-01-4		U	10
Chloroethane	75-00-3		U	10
Methylene Chloride	75-09-2		U	5
Acetone	67-64-1	25	J	100
Carbon Disulfide	75-15-0		U	5
1,1-Dichloroethene	75-35-4		U	5
1,1-Dichloroethane	75-34-3		U	5
Trans 1,2-Dichloroethene	156-60-5		U	5
Cis 1,2-Dichloroethene	156-59-2		U	5
Chloroform	67-66-3		U	5
1,2-Dichloroethane	107-06-2		U	5
2-Butanone	78-93-3		U	100
1,1,1-Trichloroethane	71-55-6		U	5
Carbon Tetrachloride	56-23-5		U	5
Bromodichloromethane	75-27-4		U	5
Vinyl Acetate	108-05-4		U	50
1,2-Dichloropropane	78-87-5		U	5
Trans-1,3-Dichloropropene	10061-02-6		U	5
Trichloroethene	79-01-6		U	5
1,1,2-Trichloroethane	79-00-5		U	5
Benzene	71-43-2		U	5
Dibromochloromethane	124-48-1		U	5
Cis-1,3-Dichloropropene	10061-01-5		U	5
2-Chloroethylvinyl Ether	110-75-8		U	10
Bromoform	75-25-2		U	5
4-Methyl-2-Pentanone	108-10-1		U	50
2-Hexanone	591-78-6		U	50
1,1,2,2-Tetrachloroethane	79-34-5		U	5
Tetrachloroethene	127-18-4		U	5
Toluene	108-88-3		U	5
Chlorobenzene	108-90-7		U	5
Ethyl Benzene	100-41-4		U	5
Styrene	100-42-5		U	5
Total Xylenes	1330-20-7		U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	98%	(90-109)
Toluene-d8	95%	(92-108)
Bromofluorobenzene	93%	(87-115)

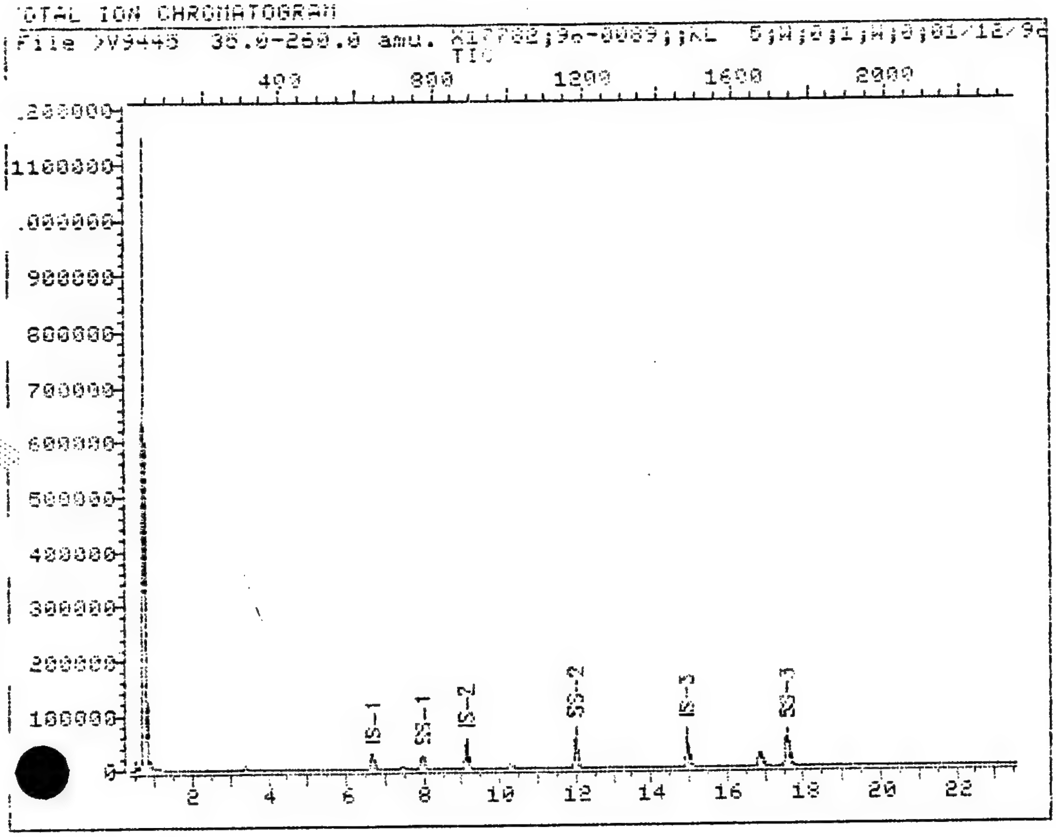
Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pa. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.

Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9445::V4
Name: X17782;96-0089;;KL
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^V9445::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14
Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 17:18
Injected at: 960112 16:54

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: MW20-4	Client I.D.	: CHARLESTON AFB, ST-27
Lab Sample Number	: X17783	Lab Project No.	: 96-0089
Date Sampled	: 01/10/96	Effective Dilution	: 1.00
Date Received	: 01/12/96	Method	: 8260A
Date Extracted/Prepared	: 01/12/96	Matrix	: WATER
Date Analyzed	: 01/12/96	Lab File No.	: >V9446
		Method Blank No.	: RB011296

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Chloromethane	74-87-3		U	10
Bromomethane	74-83-9		U	10
Vinyl Chloride	75-01-4		U	10
Chloroethane	75-00-3		U	10
Methylene Chloride	75-09-2		U	5
Acetone	67-64-1	70	J	100
Carbon Disulfide	75-15-0		U	5
1,1-Dichloroethene	75-35-4		U	5
1,1-Dichloroethane	75-34-3		U	5
Trans 1,2-Dichloroethene	156-60-5		U	5
Cis 1,2-Dichloroethene	156-59-2		U	5
Chloroform	67-66-3		U	5
1,2-Dichloroethane	107-06-2		U	5
2-Butanone	78-93-3		U	100
1,1,1-Trichloroethane	71-55-6		U	5
Carbon Tetrachloride	56-23-5		U	5
Bromodichloromethane	75-27-4		U	5
Vinyl Acetate	108-05-4		U	50
1,2-Dichloropropane	78-87-5		U	5
Trans-1,3-Dichloropropene	10061-02-6		U	5
Trichloroethene	79-01-6		U	5
1,1,2-Trichloroethane	79-00-5		U	5
Benzene	71-43-2	6		5
Dibromochloromethane	124-48-1		U	5
Cis-1,3-Dichloropropene	10061-01-5		U	5
2-Chloroethylvinyl Ether	110-75-8		U	10
Bromoform	75-25-2		U	5
4-Methyl-2-Pentanone	108-10-1		U	50
2-Hexanone	591-78-6		U	50
1,1,2,2-Tetrachloroethane	79-34-5		U	5
Tetrachloroethene	127-18-4		U	5
Toluene	108-88-3	3	J	5
Chlorobenzene	108-90-7		U	5
Ethyl Benzene	100-41-4	70		5
Styrene	100-42-5		U	5
Total Xylenes	1330-20-7	8		5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	98%	(90-109)
Toluene-d8	99%	(92-108)
Bromofluorobenzene	97%	(87-115)

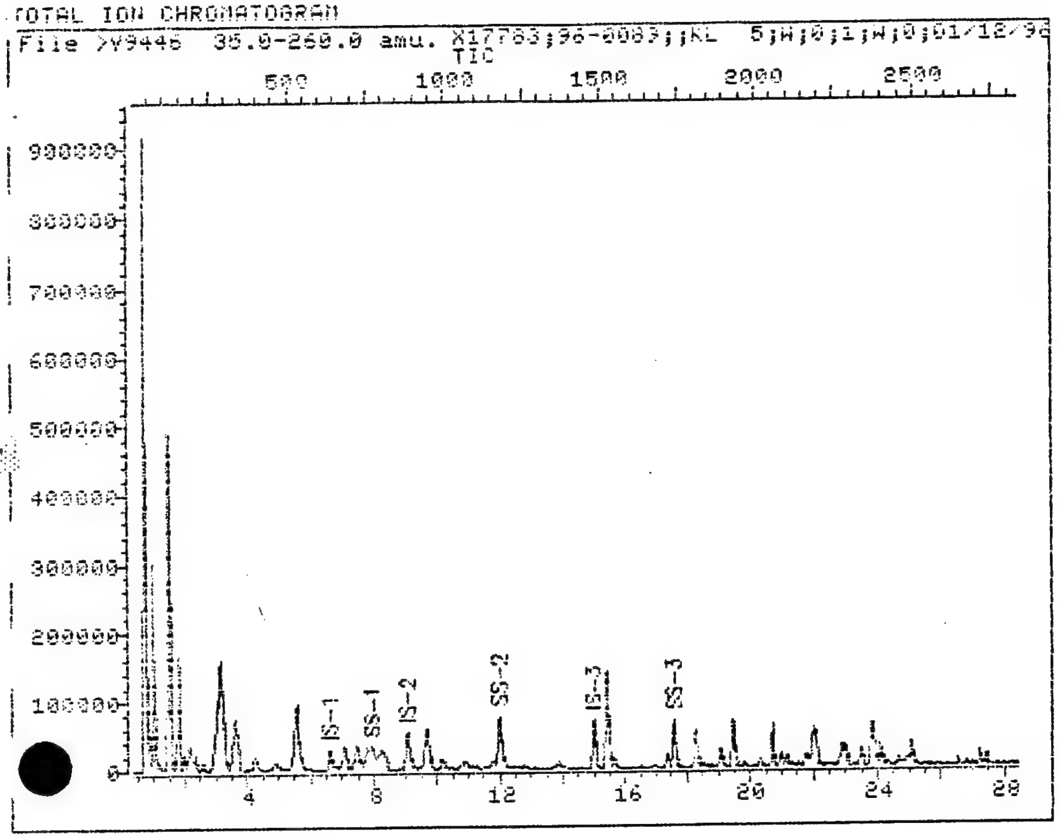
Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pg. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.

Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9446::V4
Name: X17783;96-0089;;KL
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^V9446::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14   Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 17:50
Injected at: 960112 17:20

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: MW20-12		Client I.D.	: CHARLESTON AFB, ST-27
Lab Sample Number	: X17784		Lab Project No.	: 96-0089
Date Sampled	: 01/10/96		Effective Dilution	: 1.00
Date Received	: 01/12/96		Method	: 8260A
Date Extracted/Prepared	: 01/12/96		Matrix	: WATER
Date Analyzed	: 01/12/96		Lab File No.	: >V9447
			Method Blank No.	: RB011296

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Chloromethane	74-87-3		U	10
Bromomethane	74-83-9		U	10
Vinyl Chloride	75-01-4		U	10
Chloroethane	75-00-3		U	10
Methylene Chloride	75-09-2		U	5
Acetone	67-64-1	220		100
Carbon Disulfide	75-15-0	6		5
1,1-Dichloroethene	75-35-4		U	5
1,1-Dichloroethane	75-34-3		U	5
Trans 1,2-Dichloroethene	156-60-5		U	5
Cis 1,2-Dichloroethene	156-59-2	120		5
Chloroform	67-66-3		U	5
1,2-Dichloroethane	107-06-2		U	5
2-Butanone	78-93-3		U	100
1,1,1-Trichloroethane	71-55-6		U	5
Carbon Tetrachloride	56-23-5		U	5
Bromodichloromethane	75-27-4		U	5
Vinyl Acetate	108-05-4		U	50
1,2-Dichloropropane	78-87-5		U	5
Trans-1,3-Dichloropropene	10061-02-6		U	5
Trichloroethene	79-01-6		U	5
1,1,2-Trichloroethane	79-00-5		U	5
Benzene	71-43-2	1,500	E	5
Dibromochloromethane	124-48-1		U	5
Cis-1,3-Dichloropropene	10061-01-5		U	5
2-Chloroethylvinyl Ether	110-75-8		U	10
Bromoform	75-25-2		U	5
4-Methyl-2-Pentanone	108-10-1		U	50
2-Hexanone	591-78-6		U	50
1,1,2,2-Tetrachloroethane	79-34-5		U	5
Tetrachloroethene	127-18-4		U	5
Toluene	108-88-3	130		5
Chlorobenzene	108-90-7		U	5
Ethyl Benzene	100-41-4	400		5
Styrene	100-42-5		U	5
Total Xylenes	1330-20-7	360		5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	93%	(90-109)
Toluene-d8	98%	(92-108)
Bromofluorobenzene	102%	(87-115)

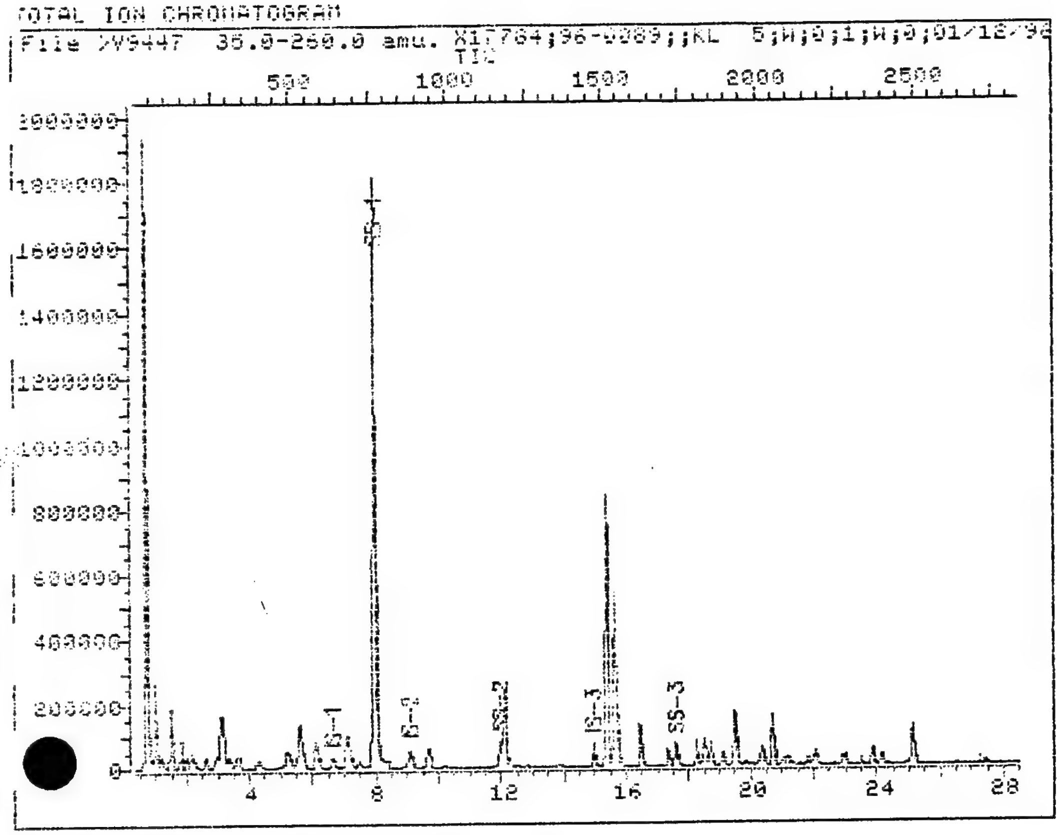
Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pg. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.

Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9447::V4
Name: X17784;96-0089;;KL
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^V9447::01
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14
Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 18:23
Injected at: 960112 17:53

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	: MW20-12	Client I.D.	: CHARLESTON AFB, ST-27
Lab Sample Number	: X17784	Lab Project No.	: 96-0089
Date Sampled	: 01/10/96	Effective Dilution	: 10.00
Date Received	: 01/12/96	Method	: 8260A
Date Extracted/Prepared	: 01/15/96	Matrix	: WATER
Date Analyzed	: 01/15/96	Lab File No.	: >V9462
		Method Blank No.	: RB011596

Compound Name	Cas Number	Conc. ug/L	EQL* ug/L
Benzene	71-43-2	1,500	50

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	96%	(90-109)
Toluene-d8	97%	(92-108)
Bromofluorobenzene	92%	(87-115)

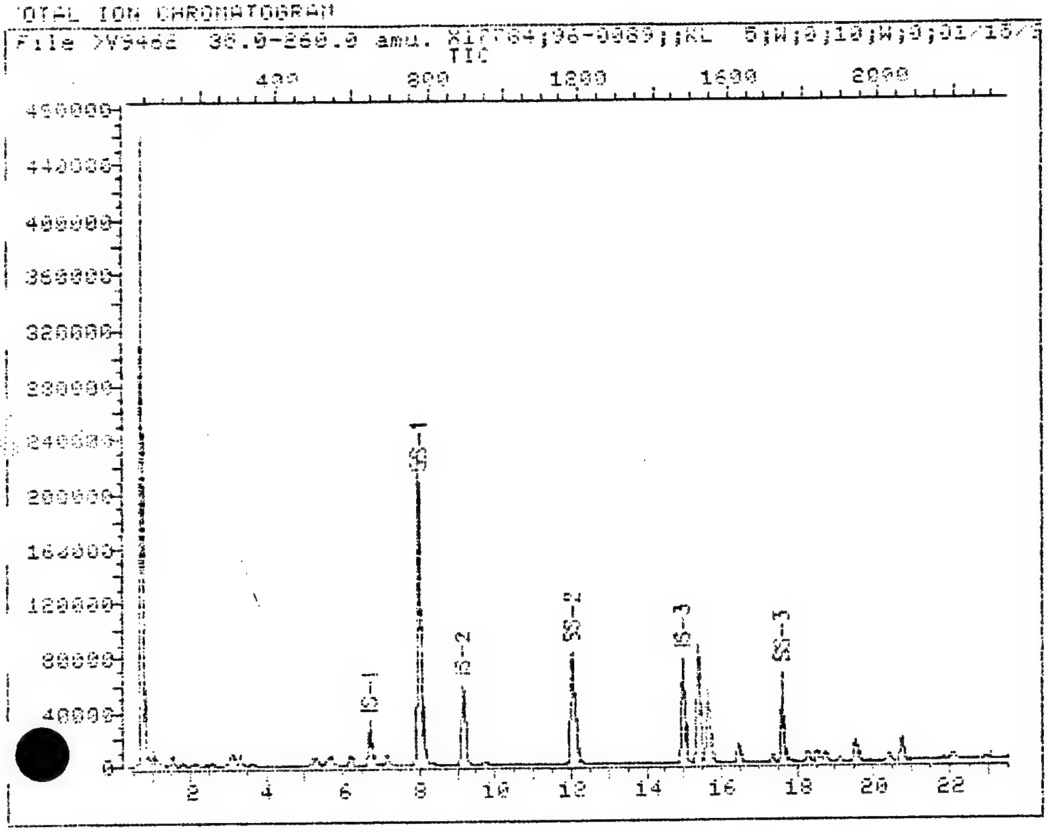
Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pa. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.

Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9462::V4
Name: X17784;96-0089;;KL
Misc: 5;W;0;10;W;0;01/15/96;0

Quant Output File: ^V9462::01
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14

Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960115 14:30
Injected at: 960115 14:06

EVERGREEN ANALYTICAL, INC.
4036 Youngfield Wheat Ridge CO 80033
(303)425-6021

VOLATILE ORGANICS ANALYSIS DATA

Client Sample Number	:	TRIP BLANK	Client I.D.	:	CHARLESTON AFB, ST-27
Lab Sample Number	:	X17786	Lab Project No.	:	96-0089
Date Sampled	:	01/10/96	Effective Dilution	:	1.00
Date Received	:	01/12/96	Method	:	8260A
Date Extracted/Prepared	:	01/18/96	Matrix	:	WATER
Date Analyzed	:	01/18/96	Lab File No.	:	>V9517
			Method Blank No.	:	RB011896

Compound Name	Cas Number	Conc. ug/L		EQL* ug/L
Chloromethane	74-87-3		U	10
Bromomethane	74-83-9		U	10
Vinyl Chloride	75-01-4		U	10
Chloroethane	75-00-3		U	10
Methylene Chloride	75-09-2		U	5
Acetone	67-64-1	11	J	100
Carbon Disulfide	75-15-0		U	5
1,1-Dichloroethene	75-35-4		U	5
1,1-Dichloroethane	75-34-3		U	5
Trans 1,2-Dichloroethene	156-60-5		U	5
Cis 1,2-Dichloroethene	156-59-2		U	5
Chloroform	67-66-3	3	J	5
1,2-Dichloroethane	107-06-2		U	5
2-Butanone	78-93-3		U	100
1,1,1-Trichloroethane	71-55-6		U	5
Carbon Tetrachloride	56-23-5		U	5
Bromodichloromethane	75-27-4		U	5
Vinyl Acetate	108-05-4		U	50
1,2-Dichloropropane	78-87-5		U	5
Trans-1,3-Dichloropropene	10061-02-6		U	5
Trichloroethene	79-01-6		U	5
1,1,2-Trichloroethane	79-00-5		U	5
Benzene	71-43-2		U	5
Dibromochloromethane	124-48-1		U	5
Cis-1,3-Dichloropropene	10061-01-5		U	5
2-Chloroethylvinyl Ether	110-75-8		U	10
Bromoform	75-25-2		U	5
4-Methyl-2-Pentanone	108-10-1		U	50
2-Hexanone	591-78-6		U	50
1,1,2,2-Tetrachloroethane	79-34-5		U	5
Tetrachloroethene	127-18-4		U	5
Toluene	108-88-3		U	5
Chlorobenzene	108-90-7		U	5
Ethyl Benzene	100-41-4		U	5
Styrene	100-42-5		U	5
Total Xylenes	1330-20-7		U	5

Surrogate Recoveries:		QC Limits
1,2 Dichloroethane-d4	96%	(90-109)
Toluene-d8	97%	(92-108)
Bromofluorobenzene	96%	(87-115)

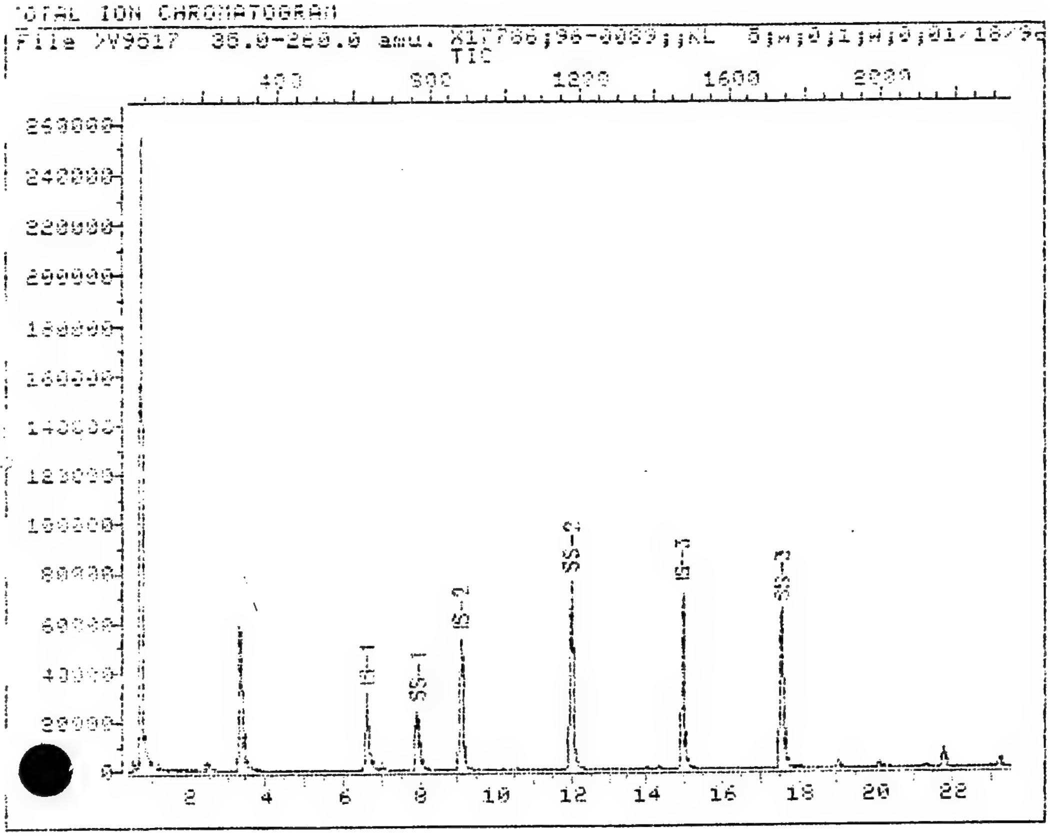
Qualifiers:
U = Compound analyzed for, but not detected above reporting limits. Reporting limits are roughly the method detection limits for reagent water
J = Indicates an estimated value when the compound is detected, but is below the EPA Estimated Quantitation Limit (EQL).
B = Compound found in blank and sample. Compare blank and sample data.
E = Compound is detected at a concentration outside the calibration limits.
* = Estimated Quantitation Limits defined in EPA SW846, Vol. 1B, Part II, pa. 8260A-34. The minimum instrument detection limits are less than the numbers shown in this column.

Unless otherwise noted all concentrations and EQL's for soils are quantitated on a dry weight basis. (NA = not applicable or not available)

Analyst

Approved

TOTAL ION CHROMATOGRAM



Data File: >V9517::V4
Name: X17786;96-0089;;KL
Misc: 5;W;0;1;W;0;01/18/96;0

Quant Output File: ^V9517::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14 Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960118 16:37
Injected at: 960118 16:13

3A

WATER VOLATILE MATRIX SPIKE/MATRIX SPIKE DUPLICATE RECOVERY

Lab Name: EVERGREEN ANALYTICAL INC.
Lab Project No. : 96-0089
Lab Sample No. : X17782
Lab File Ids. : >V9449,50

Client I.D. : CHARLESTON AFB, ST-27
Client Sample No. : MW20-2
Date Extracted : 01/12/96

COMPOUND	SPIKE ADDED (ug/L)	SAMPLE CONCENTRATION (ug/L)	MS CONCENTRATION (ug/L)	MS % REC #	QC LIMITS %REC
1,1-Dichloroethene	50	0.00	48.97	98	61-145
Trichloroethene	50	0.00	40.74	81	71-120
Benzene	50	0.00	44.07	88	76-127
Toluene	50	0.00	44.66	89	76-125
Chlorobenzene	50	0.00	45.45	91	75-130

COMPOUND	SPIKE ADDED (ug/L)	MSD CONCENTRATION (ug/L)	MSD % REC #	RPD #	QC LIMITS RPD	QC LIMITS %REC
1,1-Dichloroethene	50	50.86	102	3.8	14	61-145
Trichloroethene	50	42.10	84	3.3	14	71-120
Benzene	50	45.73	91	3.7	11	76-127
Toluene	50	43.44	87	2.8	13	76-125
Chlorobenzene	50	45.58	91	0.29	13	75-130

Column to be used to flag recovery and RPD values with an asterisk

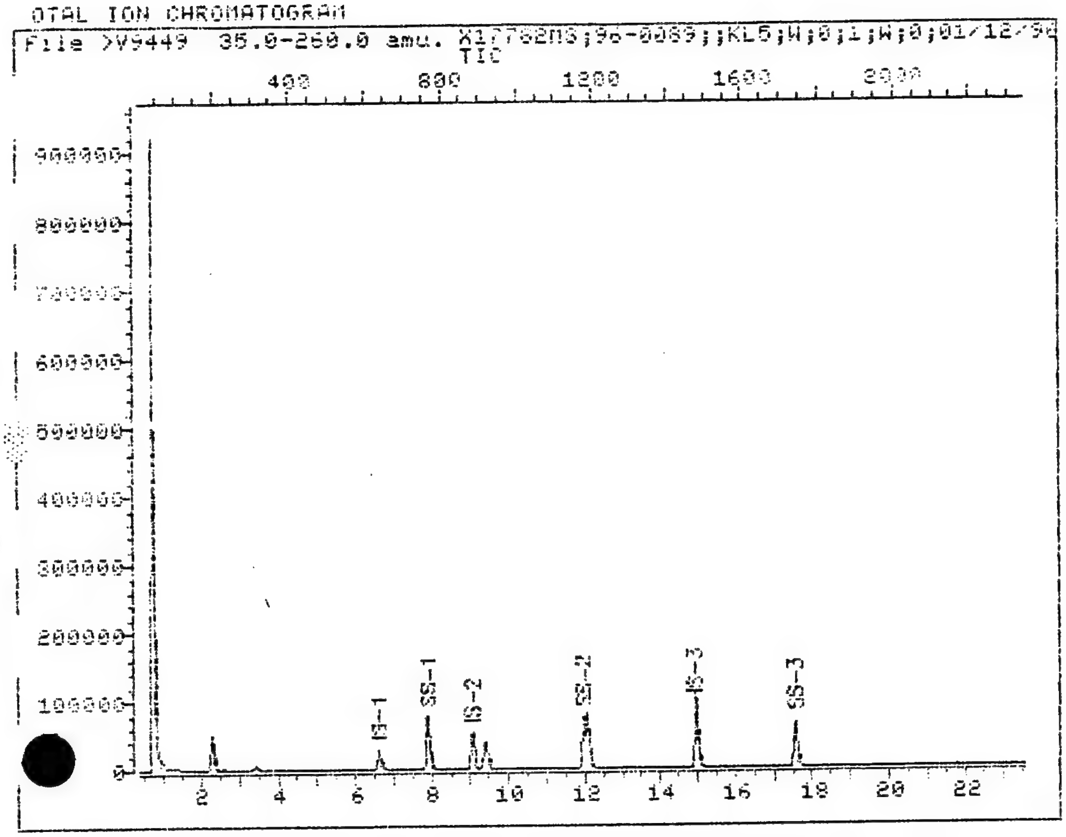
* Values outside of QC limits

RPD: 0 out of 5 outside limits.

Spike Recovery: 0 out of 10 outside limits.

Comments:

OTAL ION CHROMATOGRAM



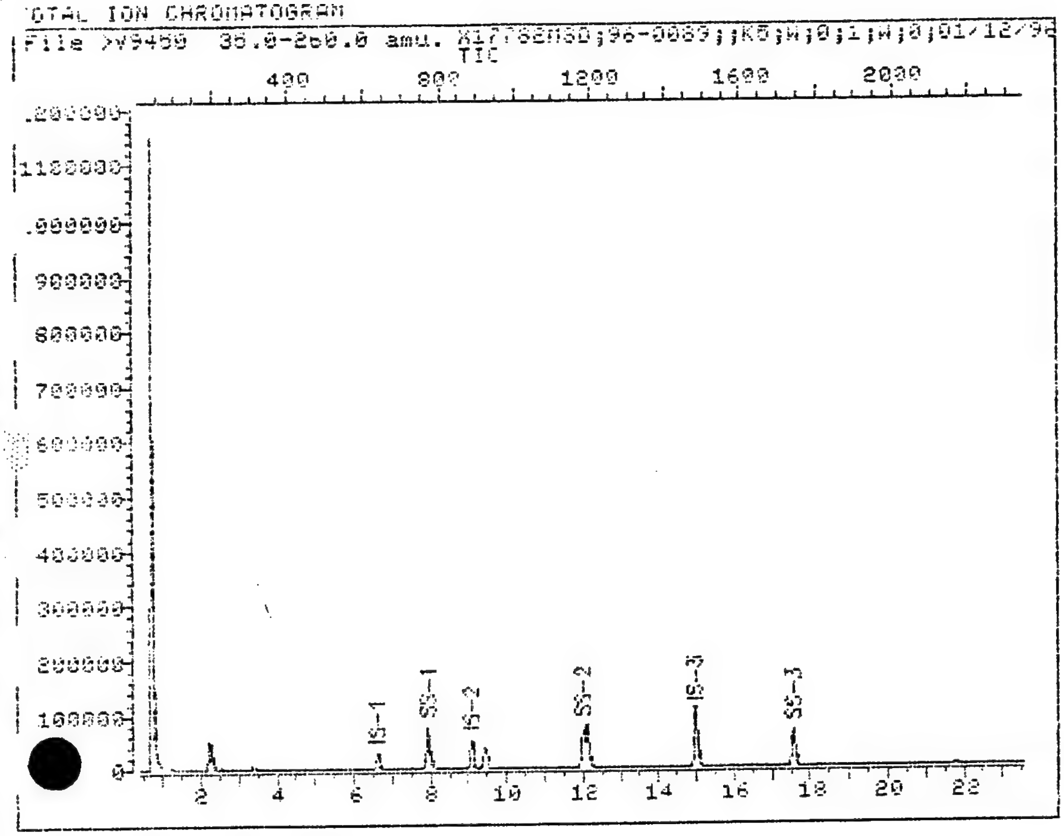
Data File: >U9449::U4
Name: X17782MS;96-0089;;KL
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^U9449::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14
Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 19:17
Injected at: 960112 18:53

TOTAL ION CHROMATOGRAM



Data File: >V9450::V4
Name: X17782MSD;96-0089;;K
Misc: 5;W;0;1;W;0;01/12/96;0

Quant Output File: ^V9450::Q1
Instrument ID: VOA 1

Id File: ID_824::QT
Title: ID FILE FOR APPENDIX NINE VOAs METHOD 8260A(8240)
Last Calibration: 960108 12:14 Last Qcal Time: <none>

Operator ID: KIM
Quant Time : 960112 19:44
Injected at: 960112 19:19

EVERGREEN ANALYTICAL, INC.
4036 Youngfield St. Wheat Ridge, CO 80033
(303) 425-6021

Methods 602/8020 and 5030/8015 Modified Data Report
Method Blank Report

Method Blank Number	: MEB1011596	Client Project Number	: CHARLESTON AFB, ST-27
Date Prepared	: 1/15/96	Lab Project Number	: 96-0089
Dilution Factor	: 125	Matrix	: SOIL
		Lab File Number	: TVB10115005
		Soil Extracted?	: YES

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	1/15/96	U	12.5	mg/kg
Benzene	71-43-2	1/15/96	U	500	ug/kg
Toluene	108-88-3	1/15/96	U	500	ug/kg
Ethyl Benzene	100-41-4	1/15/96	U	500	ug/kg
Total Xylenes (m,p,o)	1330-20-7	1/15/96	U	500	ug/kg
FID Surrogate Recovery:		106%		65%-129%	(Limits)
PID Surrogate Recovery:		93%		65%-129%	(Limits)

Notes: Total Xylenes consist of three isomers, two of which co-elute. The Xylene RL is for a single peak.

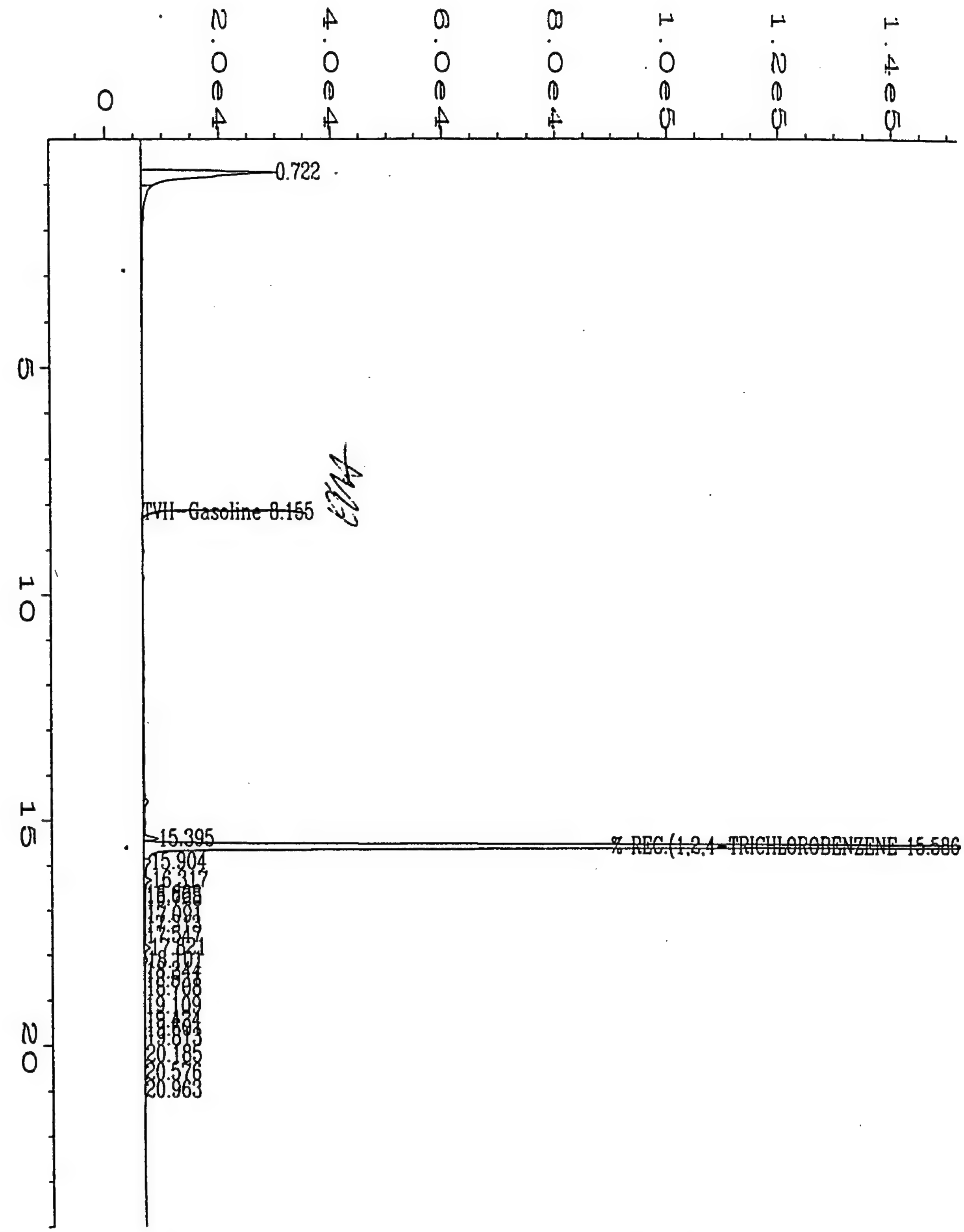
Comments:

QUALIFIERS and DEFINITIONS:

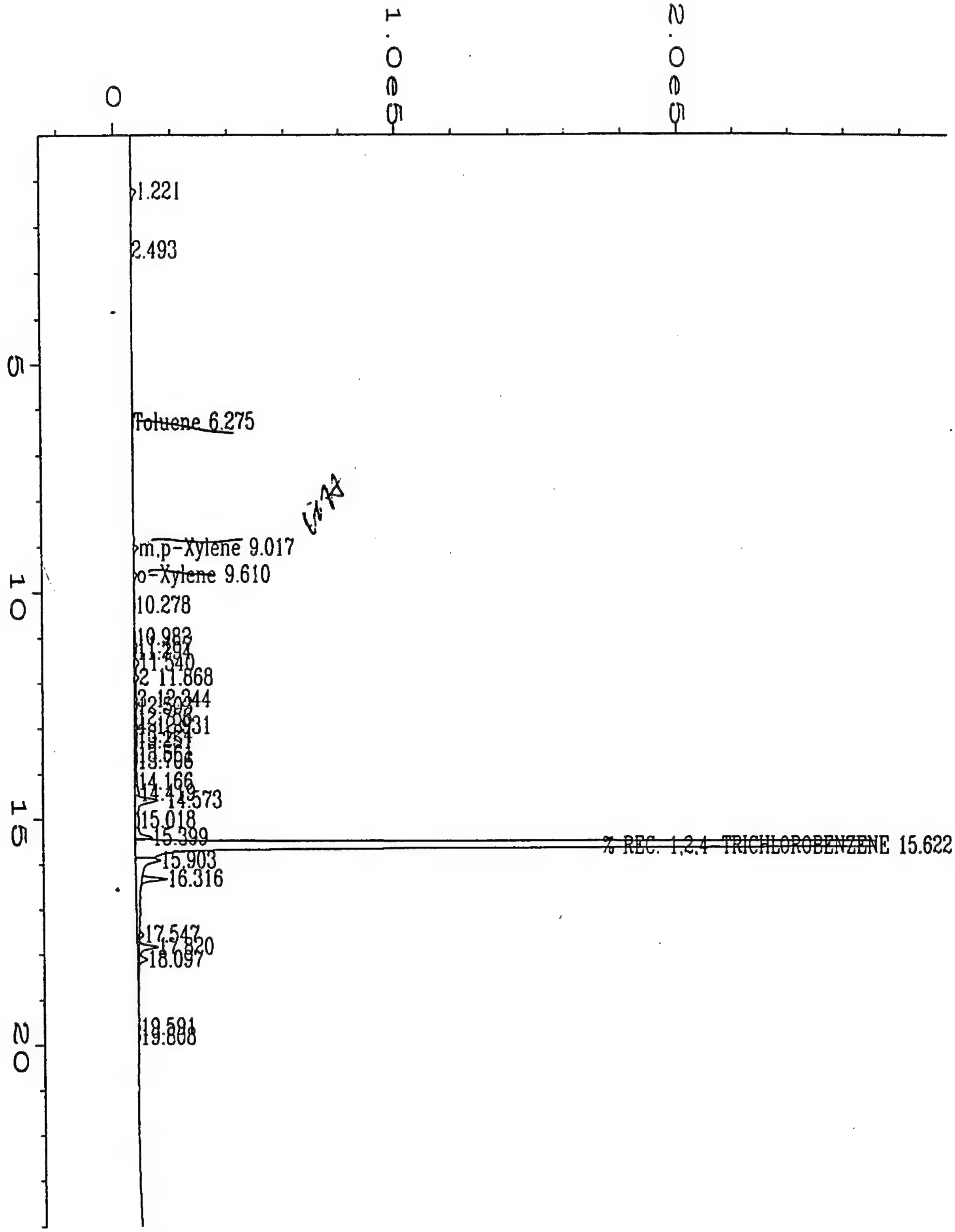
E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

M. Olecha
Analyst

K. Holloman
Approved



Data File Name	:	C:\HPCHEM\1\DATA\TVB10115\005F0101.D			
Operator	:	Mary A. Blecha	Page Number	:	1
Instrument	:	TVHBTEX1	Vial Number	:	5
Sample Name	:	MEB011596;125	Injection Number	:	1
Run Time Bar Code	:		Sequence Line	:	1
Acquired on	:	15 Jan 96 12:36 PM	Instrument Method	:	TVH1129.MTH
Report Created on	:	15 Jan 96 01:07 PM	Analysis Method	:	TVH1129.MTH
Last Recalib on	:	29 NOV 95 10:33 PM	Sample Amount	:	0
Multiplier	:	125	ISTD Amount	:	
Sample Info	:	100 ML METHANOL			



Data File Name	: C:\HPCHEM\1\DATA\TVB10115\005R0101.D			
Operator	: Mary A. Blecha	Page Number	:	1
Instrument	: TVHBTEX1	Vial Number	:	5
Sample Name	: MEB011596;125	Injection Number	:	1
Run Time Bar Code:		Sequence Line	:	1
Acquired on	: 15 Jan 96 12:36 PM	Instrument Method:		TVH1129.MTH
Report Created on:	15 Jan 96 01:07 PM	Analysis Method	:	BX10110.MTH
Last Recalib on	: 10 JAN 96 02:41 PM	Sample Amount	:	0
Multiplier	: 125	ISTD Amount	:	
Sample Info	: 100 ML METHANOL			

EVERGREEN ANALYTICAL, INC.
4036 Youngfield St. Wheat Ridge, CO 80033
(303) 425-6021

Methods 602/8020 and 5030/8015 Modified Data Report

Client Sample Number	: COMP-1	Client Project Number	: CHARLESTON AFB, ST-27
Lab Sample Number	: X17785	Lab Project Number	: 96-0089
Date Sampled	: 1/11/96	Matrix	: SOIL
Date Received	: 1/12/96	Lab File Number(s)	: TVB10115006
Date Prepared	: 1/15/96	Method Blank	: MEB1011596
FID Dilution Factor	: 125	Soil Extracted?	: YES
PID Dilution Factor	: 125		

Compound Name	Cas Number	Analysis Date	Sample Concentration	RL	Units
TVH-Gasoline	----	1/15/96	400	12.5	mg/kg
Benzene	71-43-2	1/15/96	U	500	ug/kg
Toluene	108-88-3	1/15/96	910	500	ug/kg
Ethyl Benzene	100-41-4	1/15/96	2000	500	ug/kg
Total Xylenes (m,p,o)	1330-20-7	1/15/96	9900	500	ug/kg
FID Surrogate Recovery:		122%		65%-129%	(Limits)
PID Surrogate Recovery:		99%		65%-129%	(Limits)

Notes: Total Xylenes consist of three isomers, two of which co-elute. The Xylene RL is for a single peak.

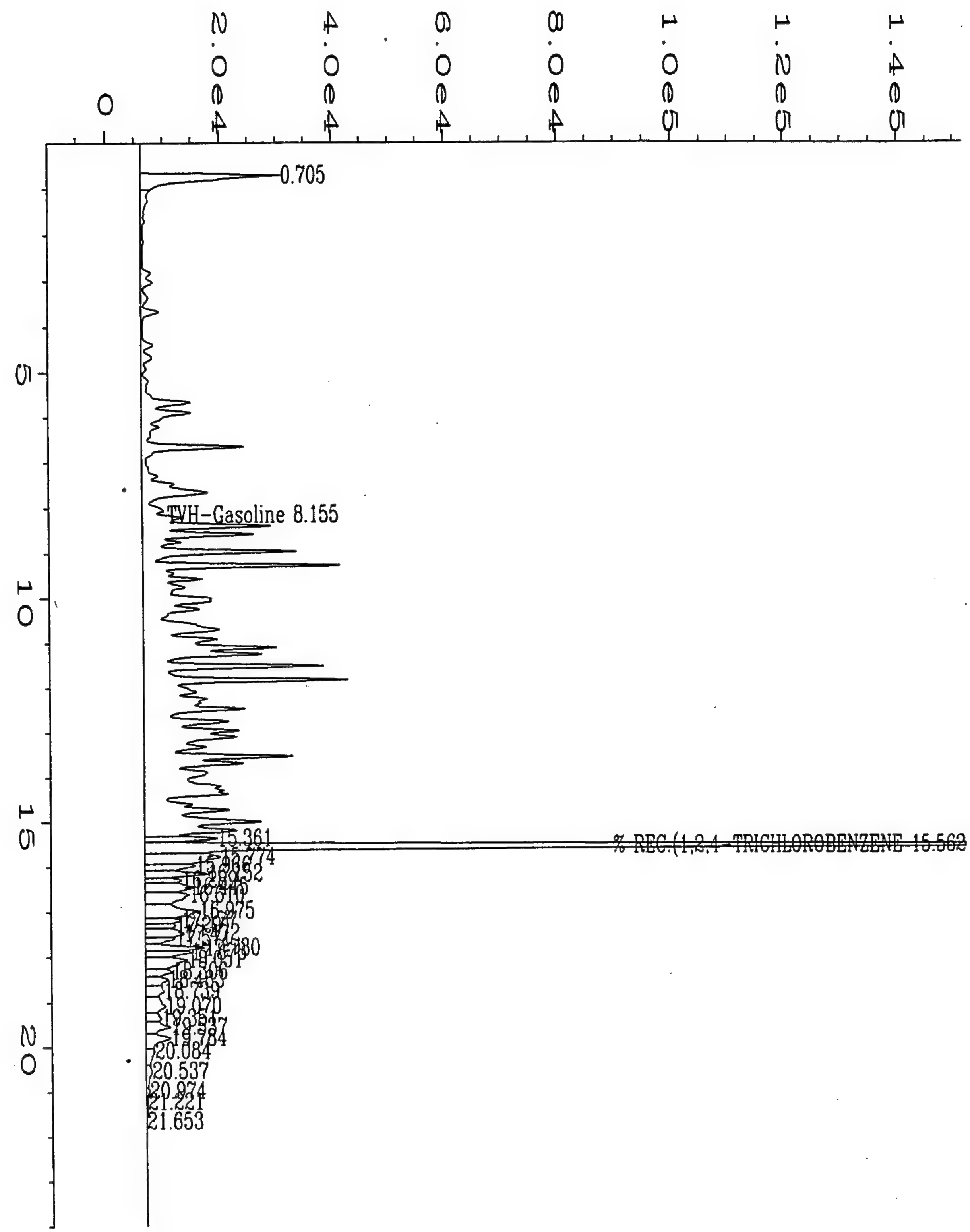
Comments:

QUALIFIERS and DEFINITIONS:

E = Extrapolated value. Value exceeds calibration range.
U = Compound analyzed for, but not detected.
B = Compound also found in the blank.
J = Indicates an estimated value when the compound is detected, but is below the Reporting Limit.
RL = Reporting Limit.
NA = Not Available/Not Applicable.
PID = Photoionization detector.
FID = Flame ionization detector.
TVH = Total Volatile Hydrocarbons.

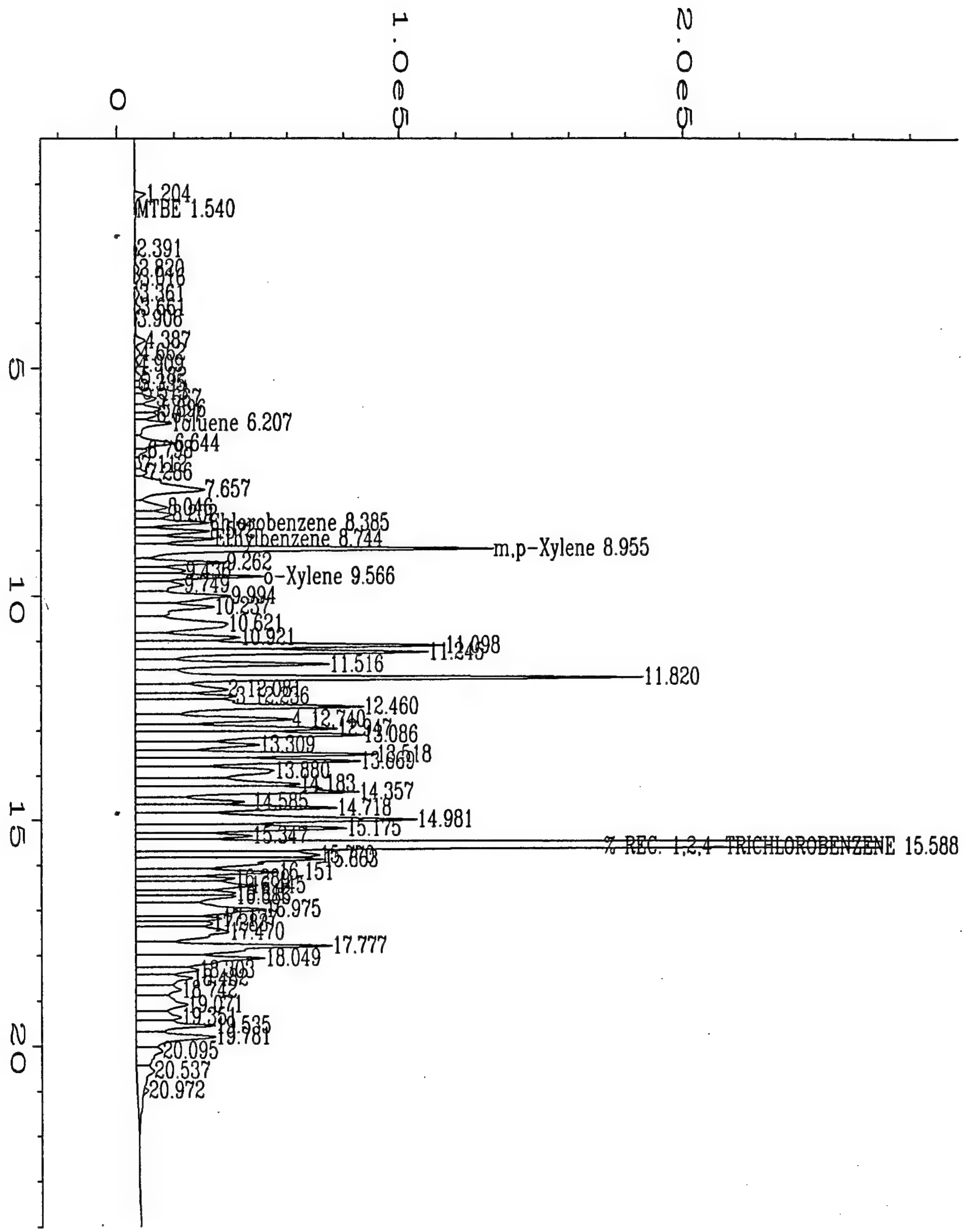
K. Hellman
Analyst

P McClell
Approved



Data File Name	:	C:\HPCHEM\1\DATA\TVB10115\006F0101.D
Operator	:	Mary A. Blecha
Instrument	:	TVHBTEX1
Sample Name	:	X17785;125
Run Time Bar Code	:	
Acquired on	:	15 Jan 96 01:16 PM
Report Created on	:	15 Jan 96 01:41 PM
Last Recalib on	:	29 NOV 95 10:33 PM
Multiplier	:	125
Sample Info	:	96-0089; COMP-1;100 ML METHANOL EXTRACT

Page Number	:	1
Vial Number	:	6
Injection Number	:	1
Sequence Line	:	1
Instrument Method	:	TVH1129.MTH
Analysis Method	:	TVH1129.MTH
Sample Amount	:	0
ISTD Amount	:	



Data File Name	:	C:\HPCHEM\1\DATA\TVB10115\006R0101.D			
Operator	:	Mary A. Blecha	Page Number	:	1
Instrument	:	TVHBTEX1	Vial Number	:	6
Sample Name	:	X17785;125	Injection Number	:	1
Run Time Bar Code	:		Sequence Line	:	1
Acquired on	:	15 Jan 96 01:16 PM	Instrument Method	:	TVH1129.MTH
Report Created on	:	15 Jan 96 01:41 PM	Analysis Method	:	BX10110.MTH
Last Recalib on	:	10 JAN 96 02:41 PM	Sample Amount	:	0
Multiplier	:	125	ISTD Amount	:	
Sample Info	:	96-0089; COMP-1;100 ML METHANOL EXTRACT			

EVERGREEN ANALYTICAL, INC.
4036 Youngfield St.
Wheat Ridge, CO 80033
(303) 425-6021

EPA 602/8020 Data Report
Laboratory Control Sample (LCS)

LCS Number	: LCS1011096-BX	Dilution Factor	: 1.00
Date Extracted/Prepared	: 1/10/96	Method	: 602/8020
Date Analyzed	: 1/1/00	Matrix	: Water
Spike Amount (ug/L) **	: 20.0	Lab File No.	: TVB10110006

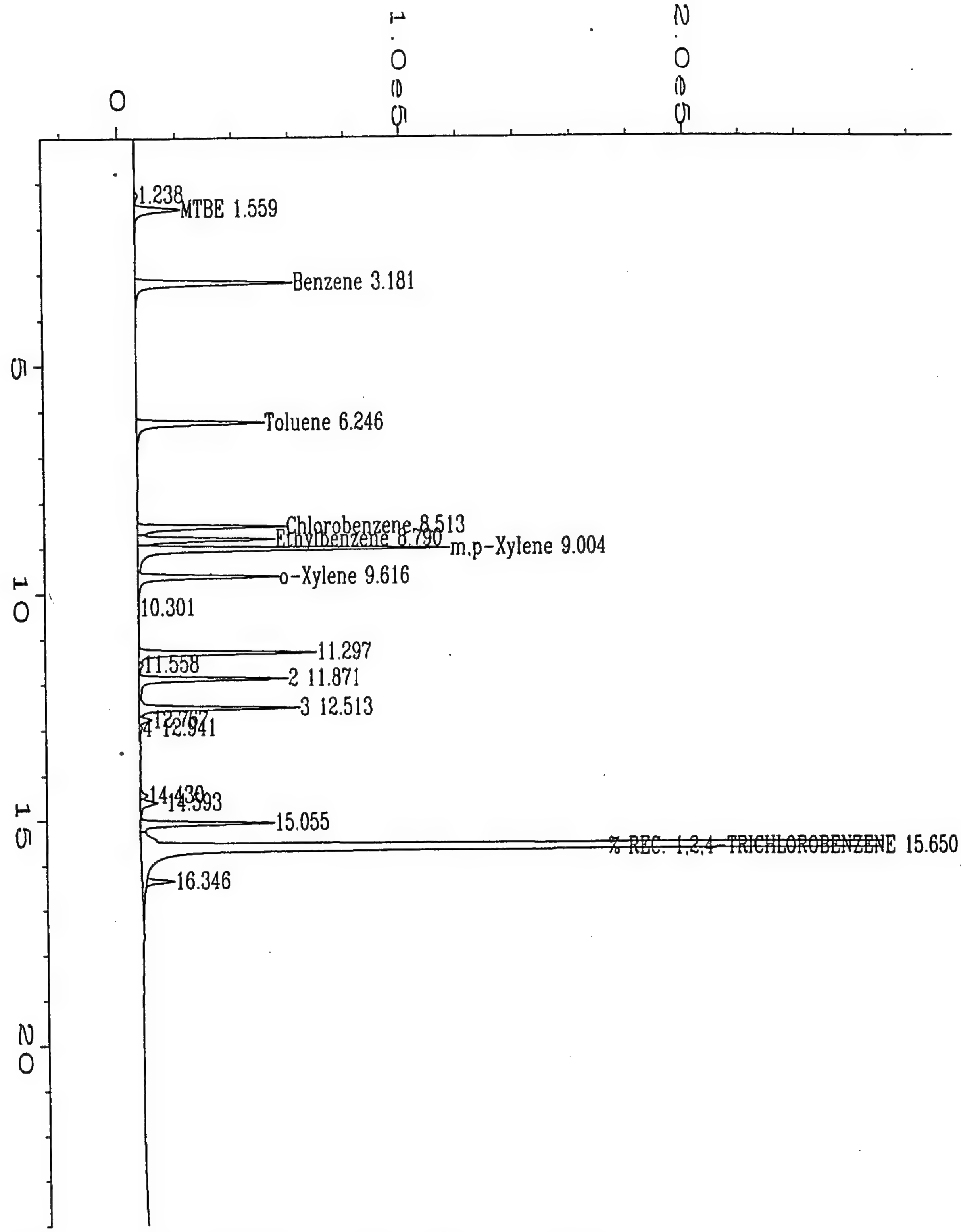
Compound Name	Cas Number	LCS Concentration (ug/L)	LCS % Recovery	QC Limit % Recovery
Benzene	71-43-2	20.5	102.5	50 - 150
Toluene	108-88-3	21.3	106.5	50 - 150
Chlorobenzene	108-90-7	21.7	108.5	50 - 150
Ethyl Benzene	100-41-4	22.3	111.5	50 - 150
m,p-Xylene	108-38-3 106-42-3	42.7	106.8	50 - 150
o-Xylene	95-47-6	22.4	112.0	50 - 150
1,3,5-Trimethylbenzene	108-67-8	NA	NA	50 - 150
1,2,4-Trimethylbenzene	95-63-6	NA	NA	50 - 150
1,2,3-Trimethylbenzene	526-73-8	NA	NA	50 - 150
1,2,3,4-Tetramethylbenzene	488-23-3	NA	NA	50 - 150
Surrogate Recovery:		102%	82%-115% (QC limits)	

NOTES: * = m,p-xylene = 40.0 ppb spike.

QUALIFIERS:
E = Extrapolated value. Value exceeds that of the calibration range.
U = Compound analyzed for, but not detected.
B = Compound found in blank and sample. Compare blank and sample data.
NA =Not available/Not analyzed.

K. Hollman
Analyst

AMcClell
Approved



Data File Name	:	C:\HPCHEM\1\DATA\TVB10110\006R0101.D			
Operator	:	Mary A. Blecha	Page Number	:	1
Instrument	:	TVHBTEX1	Vial Number	:	6
Sample Name	:	LCS1011096-BX	Injection Number	:	1
Run Time Bar Code	:		Sequence Line	:	1
Acquired on	:	10 Jan 96 03:01 PM	Instrument Method	:	TVH1129.MTH
Report Created on	:	10 Jan 96 03:25 PM	Analysis Method	:	BX10110.MTH
Last Recalib on	:	10 JAN 96 02:41 PM	Sample Amount	:	0
Multiplier	:	1	ISTD Amount	:	
Sample Info	:	#1796;P 20.0 PPB BTEXD SPIKE			

EVERGREEN ANALYTICAL, INC.
4036 Youngfield, Wheat Ridge, CO 80033
(303) 425-6021

TOTAL VOLATILE HYDROCARBONS (TVH as Gasoline)
Laboratory Control Sample (LCS)

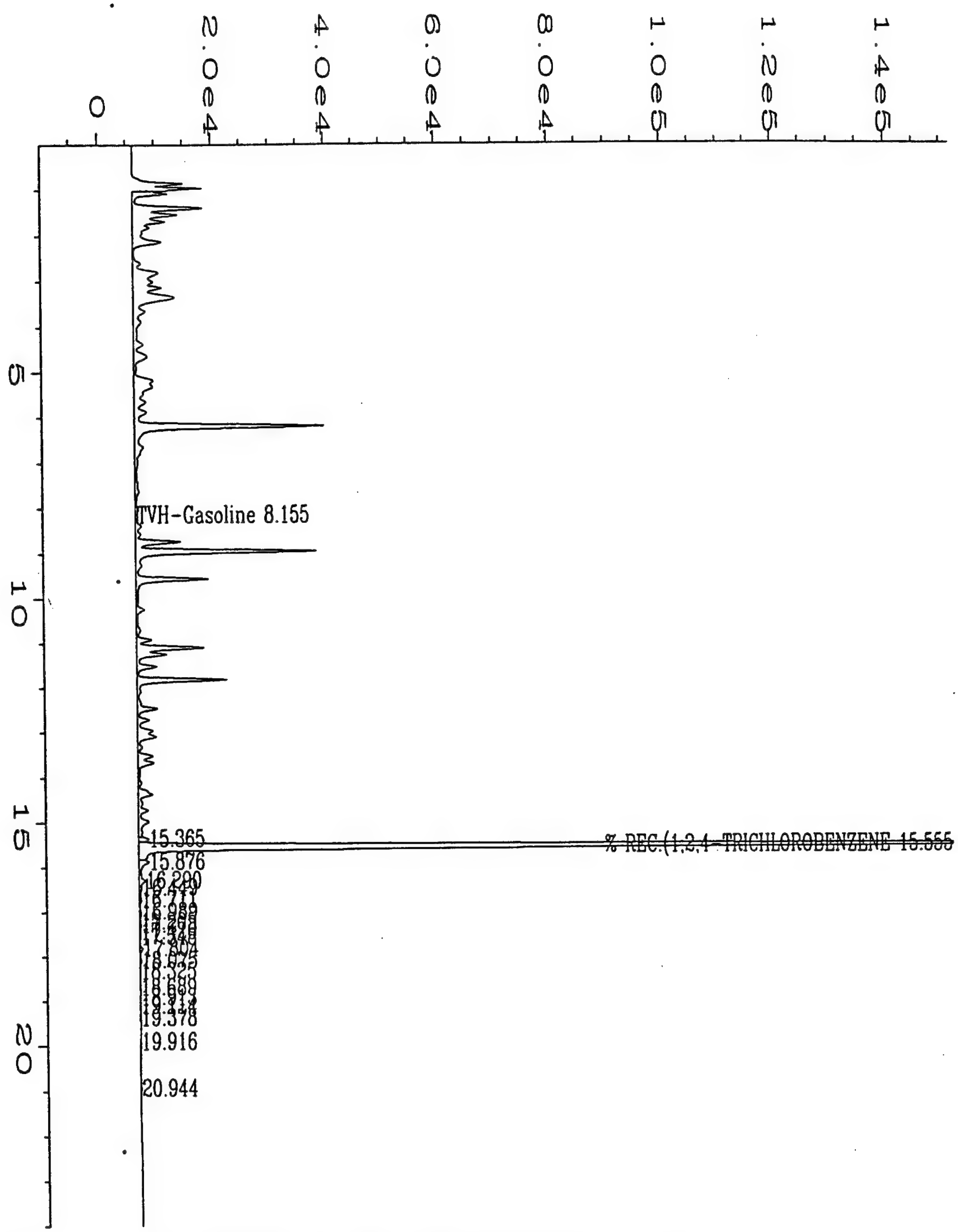
LCS Number	:	LCS1011096-GS	Matrix	:	WATER
Date Prepared	:	1/10/96	Method Numbers	:	EPA 5030/8015 Modified
Date Analyzed	:	1/10/96			
Lab File Number(s)	:	TVB10110017			

Compound Name	Theoretical Concentration (mg/L)	LCS Concentration (mg/L)	LCS % Recovery	QC Limit % Recovery
Gasoline	1.00	0.97	97%	70%-130%
Surrogate Recovery:		96%		70%-121%

QUALIFIERS
U = TVH analyzed for but not detected.
B = TVH as Gasoline found in blank also.
E = Extrapolated value. Value exceeds calibration range.
NA = Not Available/Not Applicable.

M. Blecha
Analyst

K. Hollman
Approved



Data File Name : C:\HPCHEM\1\DATA\TVB10110\017F0101.D
Operator : Mary A. Blecha
Instrument : TVHBTEX1
Sample Name : LCS1011096-GS
Time Bar Code:
Acquired on : 10 Jan 96 10:46 PM
Report Created on: 11 Jan 96 09:36 AM
Last Recalib on : 29 NOV 95 10:33 PM
Multiplier : 1
Sample Info : 1.0 PPM GASOLINE SPIKE #1797

Page Number : 1
Vial Number : 17
Injection Number : 1
Sequence Line : 1
Instrument Method: TVH1129.MTH
Analysis Method : TVH1129.MTH
Sample Amount : 0
ISTD Amount :

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(303) 425-6021

TOTAL EXTRACTABLE HYDROCARBONS (TEH-JET FUEL A)

Date Sampled	: 1/11/96	Client Project Number	: Charleston AFB, ST-27
Date Received	: 1/12/96	Lab Project Number	: 96-0089
Date Prepared	: 1/12/96	Method Number	: EPA 3500/8015 Modified

Evergreen Sample #	Dilution Factor	Client Sample #	Matrix	Analysis Date	Surrogate Recovery	Sample Result	RL	Units
SB011296	1	Soil Method Blank	Soil	1/16/96	102%	U	15.0	mg/kg
X17785	1	Comp-1	Soil	1/16/96	118%	570	15.0	mg/kg

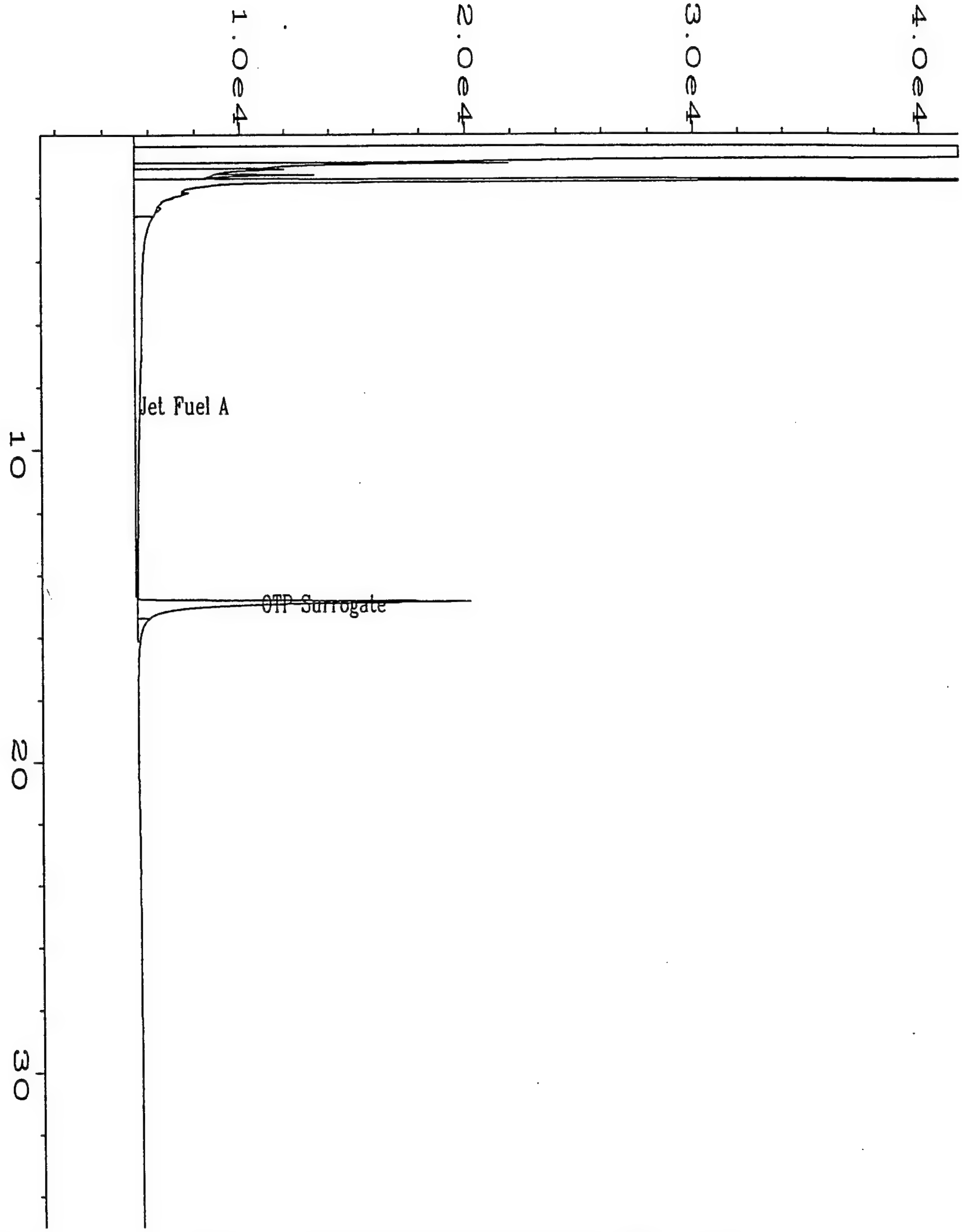
QUALIFIERS
U = TEH analyzed for, but not detected.
B = TEH-Diesel also found in blank.
E = Extrapolated value. Value exceeds calibration range.

NOTES
Surrogate = OTP
RL = Reporting Limit.

Analyst

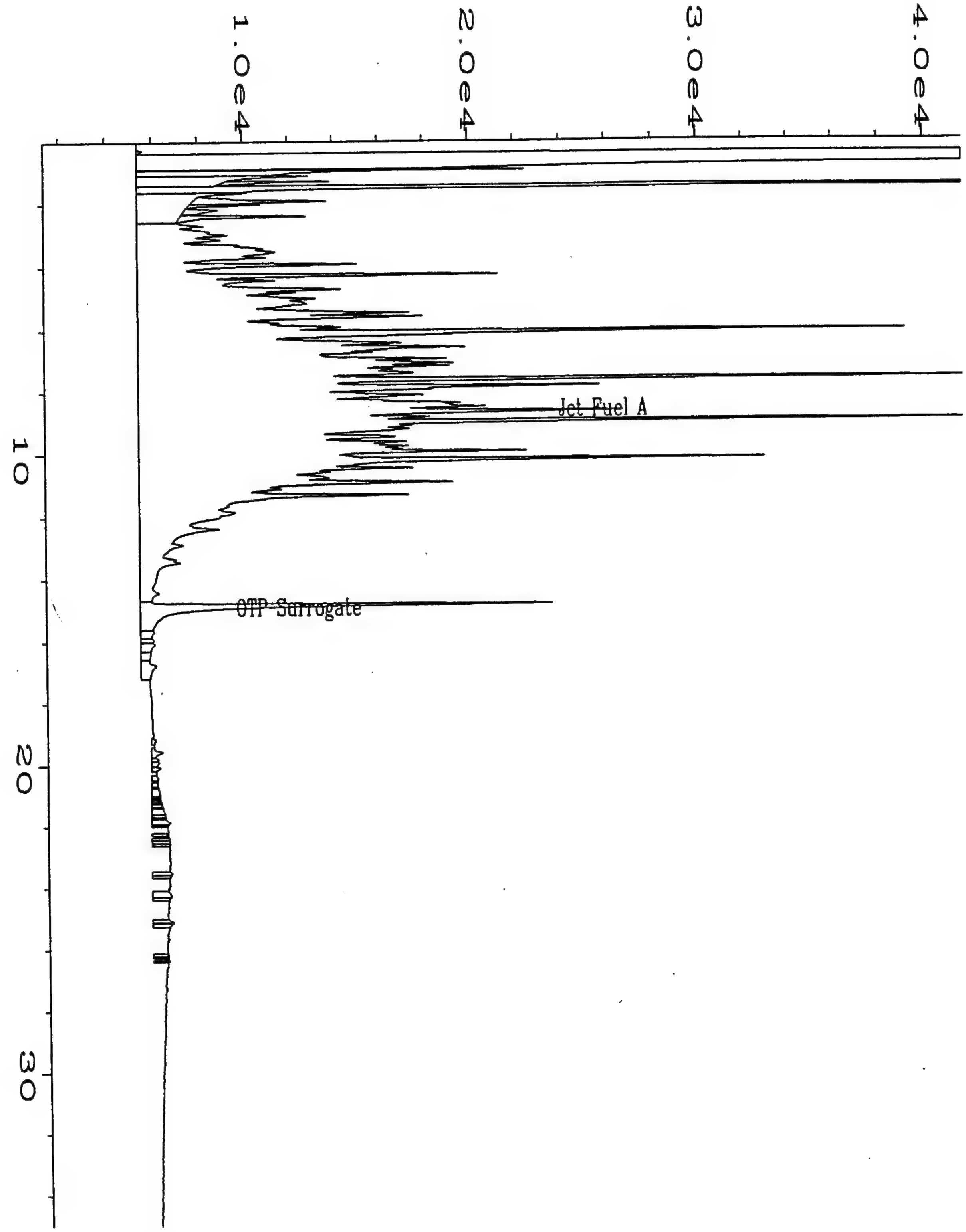
Approved

FID20089.XLS



Data File Name : C:\HPCHEM\FID2\DATA\fid20116\012F0101.D
Operator : Bill Michener
Instrument : FID2
Sample Name : SB011296
Time Bar Code:
Acquired on : 16 Jan 96 07:01 PM
Report Created on: 17 Jan 96 09:34 AM
Last Recalib on : 17 JAN 96 09:18 AM
Multiplier : 1

Page Number : 1
Vial Number : 12
Injection Number : 1
Sequence Line : 1
Instrument Method: FID2JETA.MTH
Analysis Method : JETA0116.MTH
Sample Amount : 0
ISTD Amount :



)ata File Name : C:\HPCHEM\FID2\DATA\fid20116\013F0101.D
Operator : Bill Michener
Instrument : FID2
Sample Name : X17785;1
R Time Bar Code:
A uired on : 16 Jan 96 07:53 PM
Report Created on: 17 Jan 96 09:44 AM
Last Recalib on : 17 JAN 96 09:18 AM
Multiplier : 1
Sample Info : 96-0089;Comp-1;Soil

Page Number : 1
Vial Number : 13
Injection Number : 1
Sequence Line : 1
Instrument Method: FID2JETA.MTH
Analysis Method : JETA0116.MTH
Sample Amount : 0
ISTD Amount :

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TOTAL EXTRACTABLE HYDROCARBONS (TEH as Jet Fuel A)
Laboratory Control Sample (LCS)

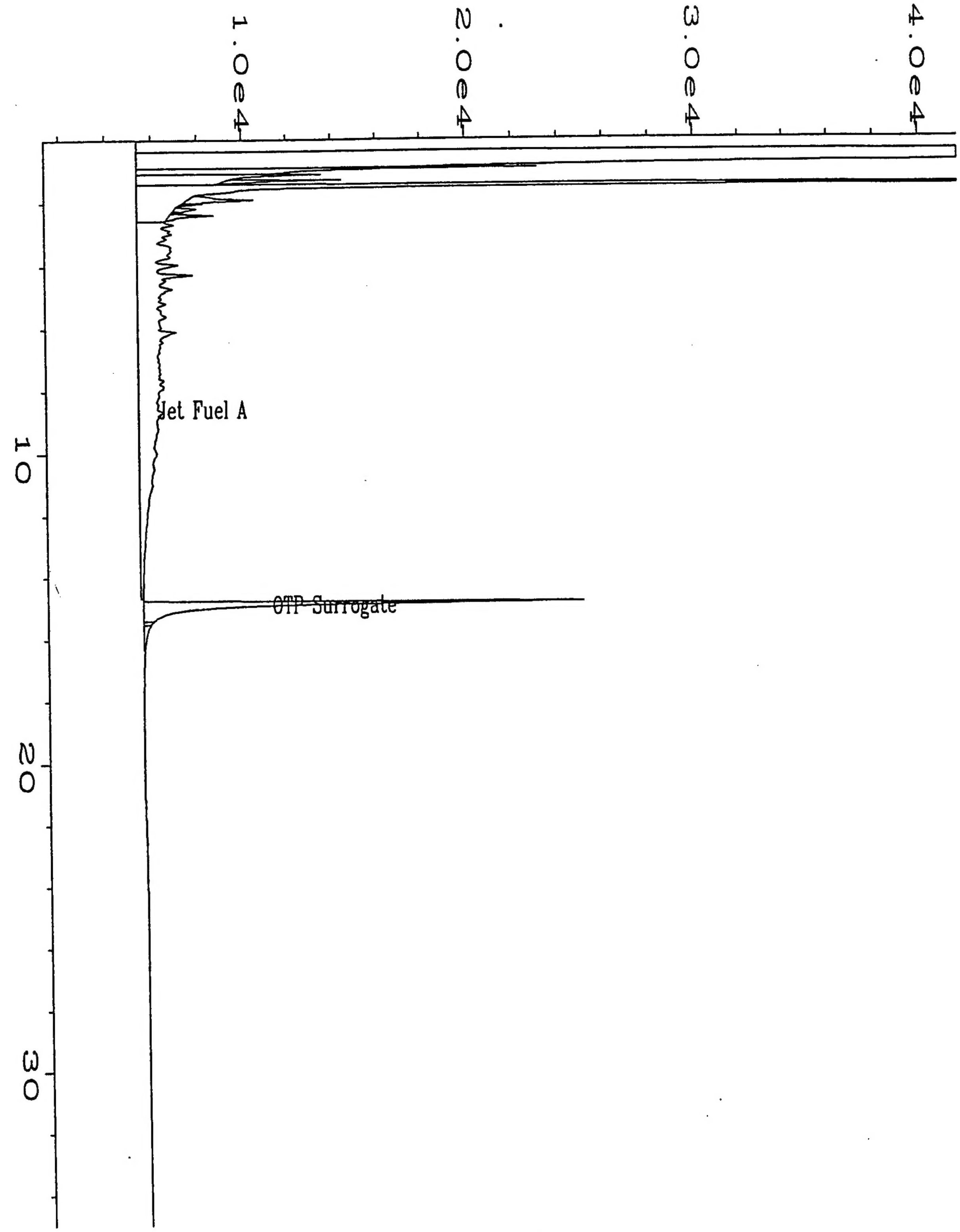
LCS Number	: LCS011296s	Matrix	: Soil
Date Prepared	: 1/12/96	Method Number	: EPA 3500/8015 Modified
Date Analyzed	: 1/16/96		
Sequence Number	: FID20116011		

Compound Name	Theoretical Concentration (mg/kg)	LCS Concentration (mg/kg)	LCS Recovery	QC Limit Recovery
Jet Fuel A	1000	667	67%	NA
TBB Surrogate % Recovery:		120%		NA

QUALIFIERS
U = TEH analyzed, for but not detected.
B = TEH-Jet Fuel A also found in blank.
E = Extrapolated value. Value exceeds calibration range.
NA=Not Available/Not Applicable.

Analyst

Approved



Data File Name : C:\HPCHEM\FID2\DATA\fid20116\011F0101.D
perator : Bill Michener
nstrument : FID2
pple Name : LCS011296s
Time Bar Code:
cquired on : 16 Jan 96 06:09 PM
eport Created on: 17 Jan 96 09:34 AM
Last Recalib on : 17 JAN 96 09:18 AM
ultiplier : 1

Page Number : 1
Vial Number : 11
Injection Number : 1
Sequence Line : 1
Instrument Method: FID2JETA.MTH
Analysis Method : JETA0116.MTH
Sample Amount : 0
ISTD Amount :

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RCRA Characteristics

Date Sampled	: 1/11/96	Client Proj	Charleston AFB, ST-27
Date Received	: 1/12/96	Lab Project	96-0089
Date Prepared	: 1/15/96	Matrix	Soil
Date Analyzed	: 1/15/96		

Evergreen Sample #	X17785
Client Sample ID.	COMP-1
Paint Filter Test[1] (% Free Liquid)	NR
Ignitability	NR
Flashpoint[2] (°F @ 620 mm Hg)	>200
Corrosivity	Non-Corrosive
pH[3]	7.79
Reactivity[4]	Non-Reactive
[a] mg H_2S/Kg waste	17
[b] mg HCN/Kg waste	<1.0

Methods:

[1] SW846 Method 9095

[2] ASTM D93 - Pensky Martens closed cup apparatus

[3] SW846 Method 7.2, parameters pH $\leq$ 2.0 to $\geq$ 12.5

[4] SW846 Method 7.3

[a] Current EPA action limits @ 500 mg H_2S/ Kg waste.

[b] Current EPA action limits @ 250 mg HCN/ Kg waste.

NR = Not Requested.

Analyst

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Analysis Report

Date Sampled	: 1/11/96	Client Project ID.	: Charleston AFB, ST-27
Date Received	: 1/12/96	Lab Project Number	: 96-0089
Date Prepared	: 1/16/96	Matrix	: Soil
Date Analyzed	: 1/16/96	Method	: SW846 9065

Evergreen Sample #	Client Sample ID.	Total Phenol	(mg/Kg)
X17785	COMP-1	<5.0*	
Method Blank	(1/16/96)	<0.05	mg/L

QUALITY ASSURANCE

		Spike Amount (mg/L)	Sample Result ** (mg/L)	Spike Result (mg/L)	% Recovery
X17785	COMP-1 Matrix Spike	0.30	<5.0	0.27	91
X17785	COMP-1 Matrix Spike Dup	0.30	<5.0	0.28	93
MS/MSD RPD					2.7

*Results reported on a dry weight basis

** Values reported in mg/L in the distillate

Analyst

Approved